G.E.C. Journal

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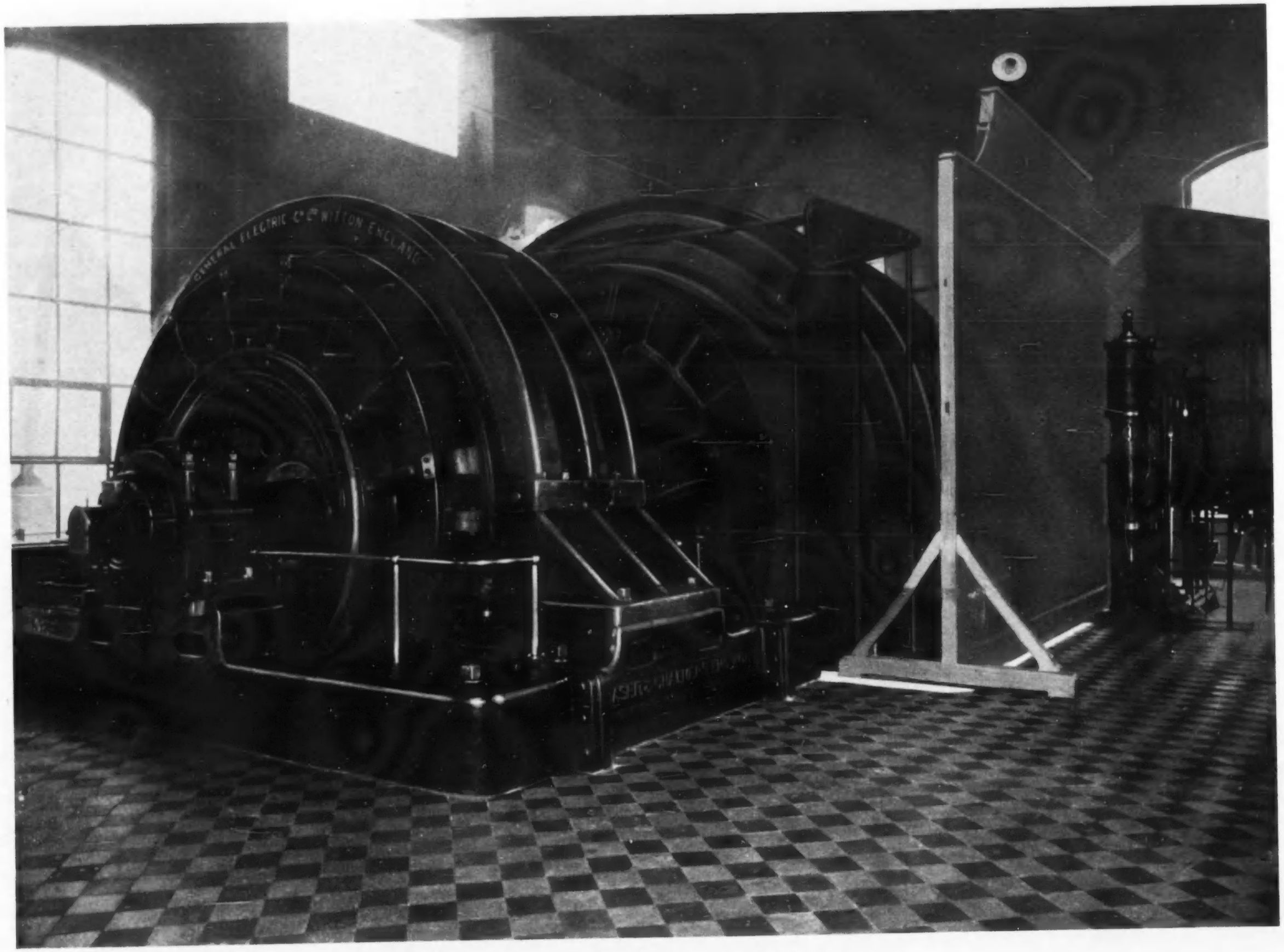


A large Ward-Leonard electric winder at a Yorkshire colliery.

G.E.C. Journal

VOL. I. AUGUST, 1930. No. 2.

The Testing of Towers for Overhead Transmission Lines.

By H. W. B. GARDINER, B.Sc. (Eng.)
Research Laboratories of The General Electric Co., Ltd., Wembley.

THE design of high-voltage overhead transmission lines involves problems which, though interdependent, are of two distinct kinds, electrical and mechanical, and of the mechanical problems, the construction of the towers is one of the most important. It is not proposed to deal here—except in a very general way—with the question of tower design, but rather to describe the methods of test used in verifying the suitability of the finished tower for its work. In order to make such a description intelligible, however, it is necessary briefly to consider the principles followed in the general planning of a transmission line.

CONSIDERATIONS IN THE PLANNING OF A TRANSMISSION LINE.

The first two questions to be settled are the terminal points of the line and the amount of power to be transmitted. The topography and climate of the terrain covered by the line are then studied, and the possible routes are tentatively determined. The voltage has then to be decided, this depending partly on purely electrical considerations and partly on others of an economic nature. At this stage the dimensions and material of the conductor itself begin to be defined, and it becomes possible to consider how it shall be supported. Many factors have to be taken into account in designing the supporting towers. The span length, for instance, depends to some extent on the conductor material and section. It is limited by the fact that, as it increases, so the conductor stresses, the height of the towers and the cross-arm stresses become greater; on the other hand, the number of towers required for the whole line decreases. The normal span is finally decided by balancing these factors to obtain the economic optimum length. It is not usually possible to work with one type of tower only; three or four designs are usually adopted as standard to suit various degrees of deviation of the line from the straight. Thus, in a typical scheme one design might be adopted as suitable for straight sections of line, and for deviations up to 5 degrees; another for deviations from 5 degrees to 30 degrees, and a third for deviations from 30 degrees to 60 degrees. Outlines of typical towers are shown in fig. 1. Towers of special design will probably also be necessary for parts of the line where the standard types are unsuitable. For example, extra long spans may be required in some places for crossing rivers. Every effort, however, is made to keep down the number of special types, owing to the extra expense involved.

WORKING LOADS ON TOWERS.

The designer has next to consider the working conditions of the line as they affect the tower loadings. These cannot be determined accurately, and a specification must therefore be prepared, definitely stating the conditions which it is necessary that the towers should be able to withstand. This specification must deal with all the factors which affect the tower loadings, such as the maximum wind pressure, the maximum temperature range, and the maximum amount of ice or snow which the conductors are expected to carry.

It is also usual to stipulate that the towers must be able to resist forces due to the breaking of one

A full description of the testing plant mentioned in this article appeared in "The Engineer" Vol. 149, page 556, 1930. Fig. 2 is reproduced by permission of "The Engineer."

or more conductors, so that the towers at each end of the broken span shall not be destroyed or overstressed when conductor breakage occurs.

The factor of safety to be employed is often specified by the regulations of the country or territory in which the line is to be erected. It is sometimes considered that as the maximum loads given in the specification are abnormal, no safety factor is required. It must be remembered, however, that though these loads are severe, they are capable of attainment, and some margin must be allowed for other factors which cannot exactly be defined. For instance, the forces on the towers are often applied or varied suddenly; again, it is necessary to provide for the slight but unavoidable differences between similar towers due to permitted tolerances in manufacture, and to allow for other variations which occur throughout the line, such as the nature of the ground and type of foundations employed. It is usual to adopt a lower factor of safety for broken conductor conditions, as these are admittedly abnormal.

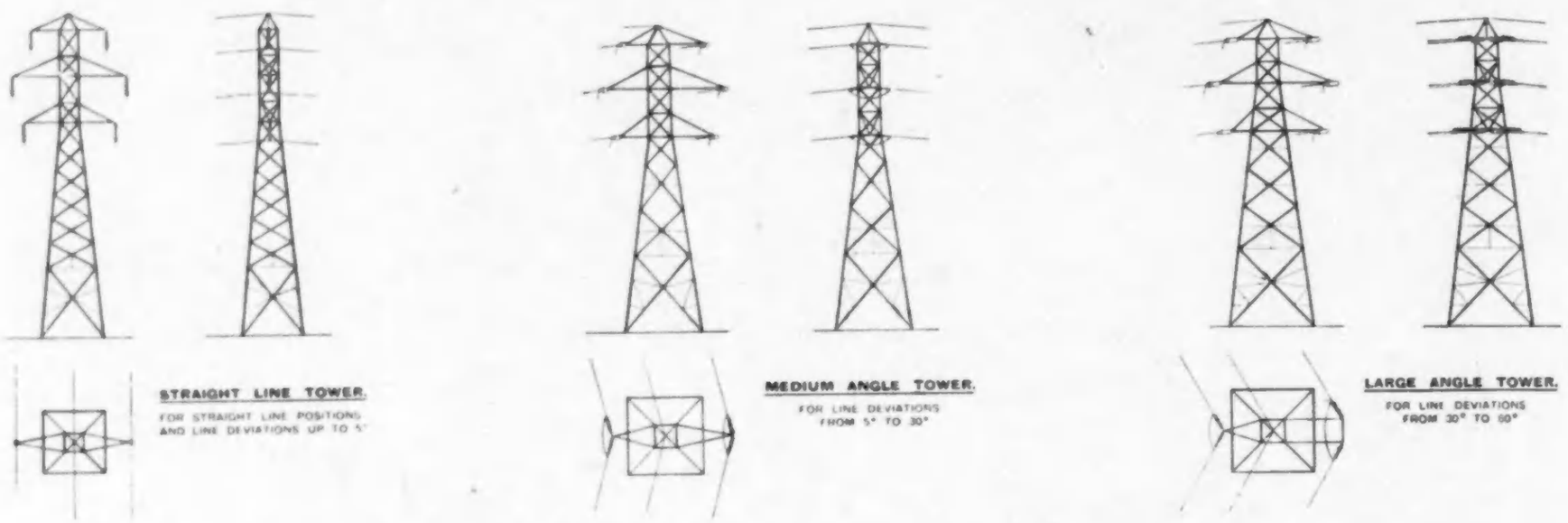

STRAIGHT LINE TOWER.
FOR STRAIGHT LINE POSITIONS AND LINE DEVIATIONS UP TO 5°
MEDIUM ANGLE TOWER.
FOR LINE DEVIATIONS FROM 5° TO 30°
LARGE ANGLE TOWER.
FOR LINE DEVIATIONS FROM 30° TO 60°

Fig. 1.—Typical standard towers for a 110 kV line.

DESIGN OF THE TOWERS.

A detailed specification on these lines enables the engineer to calculate the actual forces to which the towers will be subjected, and these are used as a basis for the design of the actual towers. There are many combinations of forces which can be applied to a tower representing various conditions of loading, and the design must ensure that all of these can be successfully withstood. As an example, a designer might be working on a medium angle tower to take line deviations of from 5 degrees to 30 degrees, for use on a 110 kV line having two three-phase circuits and one earth conductor, with a span of 1,500 feet for minimum deviation and 1,000 feet for maximum deviation conditions. There are then two normal working load combinations to be considered. These are:

(1). Maximum working loads, minimum deviation.

(2). Maximum working loads, maximum deviation.

Again, allowance must be made for broken conductor conditions. Such a tower would probably have to be strong enough to sustain forces due to any four conductors being broken, involving 30 different possible combinations. Of these, a few (usually about four) will produce maximum stresses in some members of the tower, and are of importance to the designer. The remainder need not be considered as they do not stress the tower so highly, and can easily be resisted by a tower suited to the more critical loadings. Thus, there will be about six load combinations in all to be considered.

OBJECTS OF THE TESTS.

When the tower designs are completed it is the duty of the engineer representing the authority or

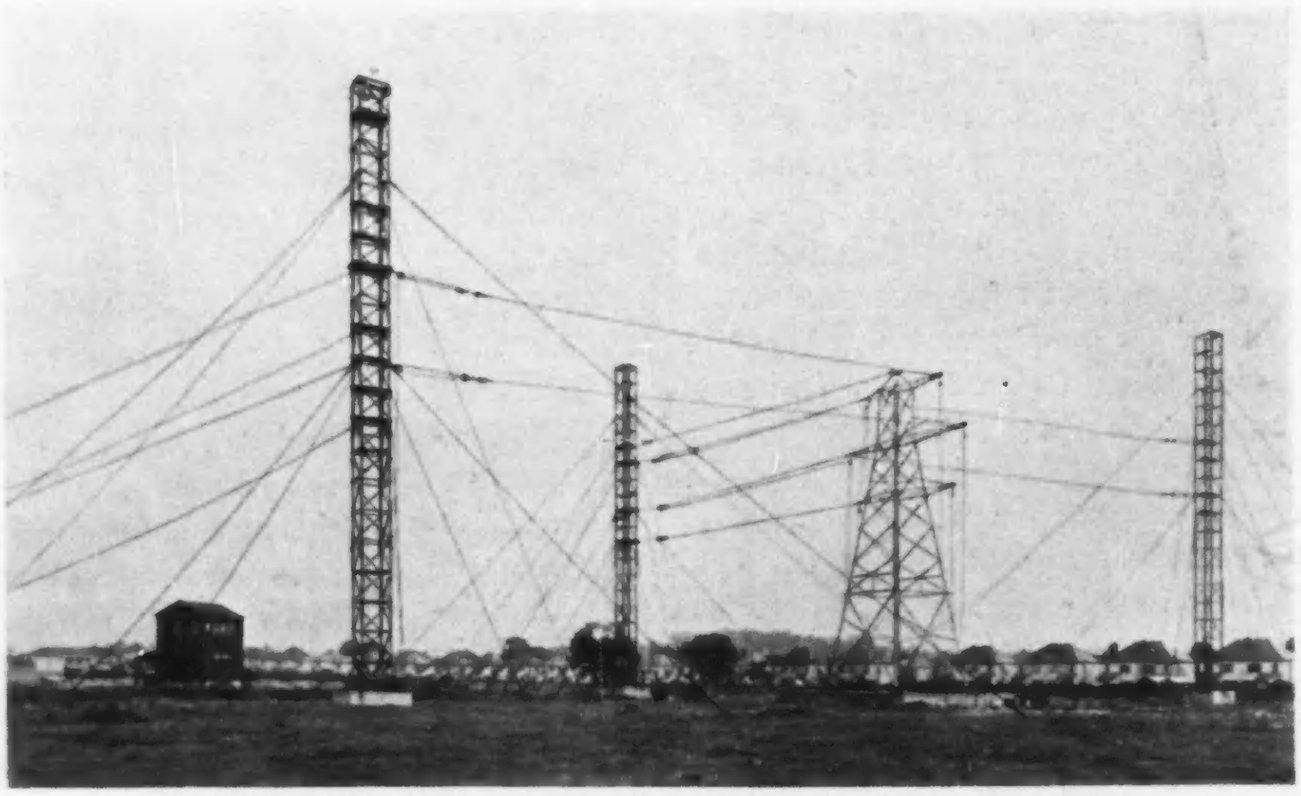


Fig. 2.—Testing plant for overhead transmission towers at the G.E.C. Research Laboratories.

company for whom the line is being erected to assure himself that the towers conform to the specification, and are suitable for their intended purpose. For short lines of lesser importance this has sometimes been done by checking the designer's figures, calculations and drawings to see that they follow

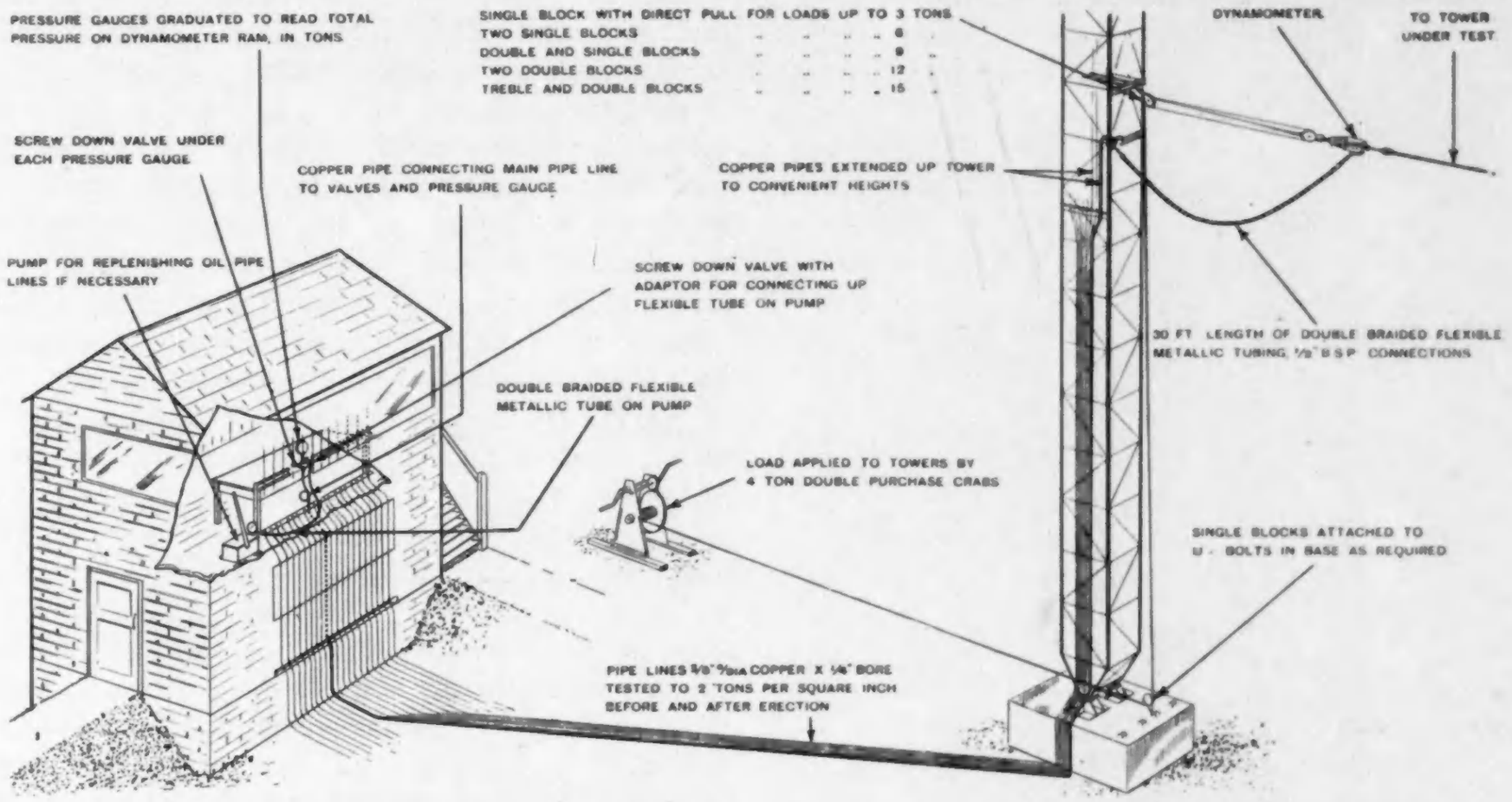

PRESSURE GAUGES GRADUATED TO READ TOTAL PRESSURE ON DYNAMOMETER RAM, IN TONS
SINGLE BLOCK WITH DIRECT PULL FOR LOADS UP TO 3 TONS
TWO SINGLE BLOCKS " " " " 6 "
DOUBLE AND SINGLE BLOCKS " " " " 9 "
TWO DOUBLE BLOCKS " " " " 12 "
TREBLE AND DOUBLE BLOCKS " " " " 15 "
DYNAMOMETER
TO TOWER UNDER TEST
SCREW DOWN VALVE UNDER EACH PRESSURE GAUGE
COPPER PIPE CONNECTING MAIN PIPE LINE TO VALVES AND PRESSURE GAUGE
COPPER PIPES EXTENDED UP TOWER TO CONVENIENT HEIGHTS
PUMP FOR REPLENISHING OIL PIPE LINES IF NECESSARY
SCREW DOWN VALVE WITH ADAPTOR FOR CONNECTING UP FLEXIBLE TUBE ON PUMP
30 FT LENGTH OF DOUBLE BRAIDED FLEXIBLE METALLIC TUBING ½" B.S.P. CONNECTIONS
DOUBLE BRAIDED FLEXIBLE METALLIC TUBE ON PUMP
LOAD APPLIED TO TOWERS BY 4 TON DOUBLE PURCHASE CRABS
SINGLE BLOCKS ATTACHED TO U - BOLTS IN BASE AS REQUIRED
PIPE LINES ⅜" ⁹⁄₁₆ DIA COPPER X ⅛" BORE TESTED TO 2 TONS PER SQUARE INCH BEFORE AND AFTER ERECTION

Fig. 3.—Arrangement of dynamometer pipe lines, control room and winches.

rational methods. In each method of design, however, there are factors which are not susceptible to rigid calculation and the result depends to a large extent on the judgment of the designer. It is therefore considered desirable to check the correctness of the design by the more reliable method of making full scale tests on an actual tower, thus eliminating any doubts that may arise from the necessity for basing the design on somewhat controversial data. These tests enable the strength of the tower to be determined accurately and impartially.

Fig. 4.—Interior of control room.

TOWER TESTING PLANT.

In order to carry out such tests a plant capable of dealing with all sizes of towers of standard type up to the largest yet contemplated was installed at the G.E.C. Research Laboratories, Wembley. A general view of the plant is seen in fig. 2 which shows a test being carried out on a double-circuit wide angle tower for the British 132 kV Grid. The tower to be tested is erected on a reinforced concrete bed about 40 feet square, weighing 850 tons. On three sides of this base are placed frameworks 100 feet high, from which the loads are applied to the tower under test. To avoid bending stresses in the frameworks, they are mounted at the lower end on hinged joints, and are kept vertical by guy ropes. At each five foot interval up the frameworks is arranged a horizontal frame from which loads may be applied. Beams are placed on these frames at the heights of the cross-arms, connection being made from the end of a beam to the crossarm of the tower by a tension rope and pulley blocks in which the winch rope is reeved. The forces on the tower are measured by hydraulic dynamometers attached to the tension ropes, as shown in fig. 3. The dynamometers each consist of a hydraulic cylinder connected by a yoke to the pulley block. In this cylinder slides a plunger loaded by a second yoke attached to the tension rope,

the oil in the cylinder being compressed to a pressure proportional to the force in this rope. Fig. 3 shows how this pressure is transferred to gauges in the control room, the interior of which is seen in fig. 4. The gauges are calibrated directly in tons, and beneath them at the front of the table are push buttons working the signals to the winches

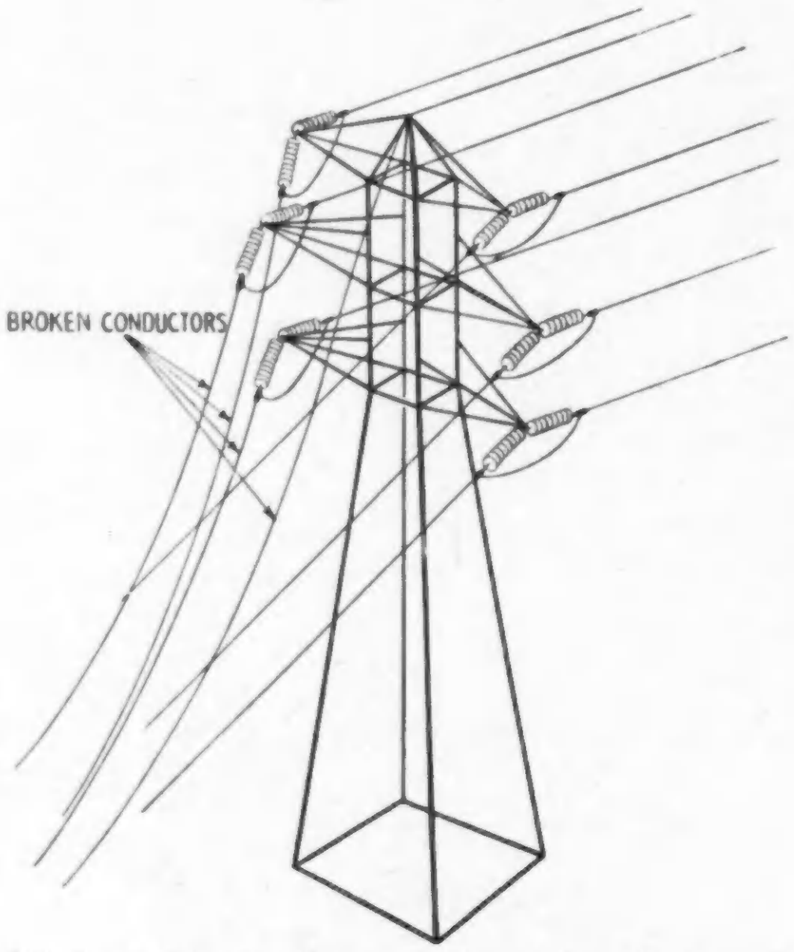


Fig. 5.—Diagram of tower with earth conductor and three line conductors broken.

placed at the rear of the frameworks and applying the respective loads.

Eight transverse pulls of 15.6 tons can be applied simultaneously with an equal number of longitudinal pulls of 9 tons each. The overturning moment that can be applied to the tower exceeds 10,000 tons-feet.

DETERMINATION OF TEST LOADS.

For the reason already mentioned, it is not necessary in testing a tower to apply all the combinations of loading which are possible. Certain conditions of loading stress various bars to their maximum extent, other loading conditions being less severe. Thus, the corner legs are often stressed most severely with test loads representing normal conditions, when a severe bending moment is applied to the tower. In some cases, however, a number of conductors broken in the same span will give test loads which stress the legs to a greater extent than loads representing normal conditions. The diagonals are usually stressed most severely when heavy torsional forces are applied to the tower by broken conductors in adjacent spans at opposite crossarm ends. It is usually possible to choose three or four of the critical load conditions to be applied as tests which, when carried out, have tested every important bar in the structure to its maximum stress.

In planning a test, the working loads on the tower for the particular condition are ascertained, and these are resolved in directions parallel to the axes of the tower and then multiplied by the appropriate factor of safety to obtain the test loads.

Considering, for instance, a medium angle double circuit tower for a 110 kV line with a steel cored aluminium conductor of 0.15 sq. in. equivalent copper section, and a span of 800 feet, the working loads, and corresponding test loads representing normal and broken conductor conditions, for a position of maximum deviation (30 degrees) are given in the accompanying table. The tower would be designed to withstand four broken conductors, and in a typical case such as that shown in fig. 5, where the earth conductor and three line conductors are broken, the corresponding test loads are given in fig. 6A. Other tests which would probably be imposed to test the tower fully are seen in figs. 6B, 6C, and 6D.

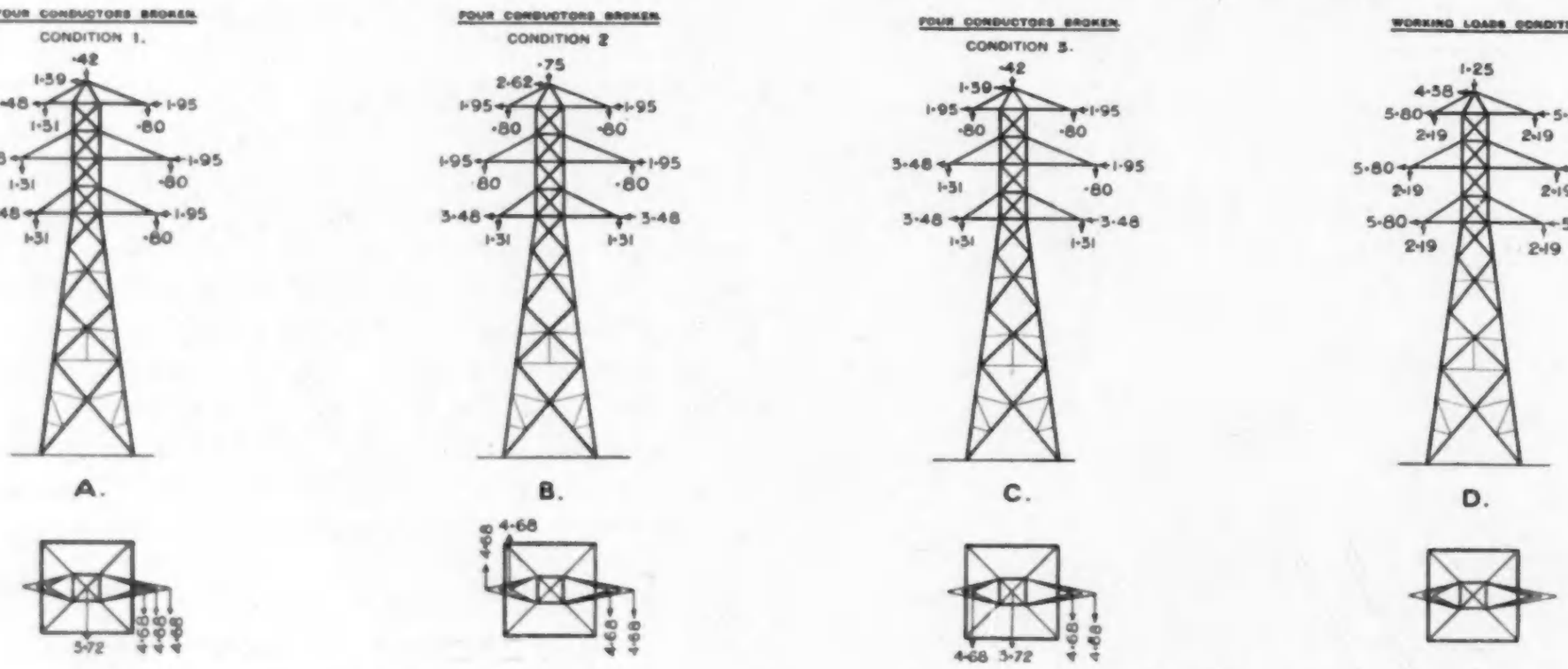


Fig. 6.—Test loads of medium angle towers for a 110 kV line. The figures give loads in tons.

TEST LOADS FOR MEDIUM ANGLE TOWER, WITH LINE DEVIATION OF 30°.

	Working Load.	Test Load, Normal conditions Factor of Safety 2.5.	Test Load, Broken Conductor conditions Factor of Safety 1.5
Line Conductor, Unbroken.			
Longitudinal Load	—	—	—
Transverse Load	2.32	5.80	3.48
Vertical Load..	.875	2.19	1.31
Line Conductor, Broken.			
Longitudinal Load	3.12	—	4.68
Transverse Load	1.30	—	1.95
Vertical Load..	.53	—	.80
Earth Conductor, Unbroken.			
Longitudinal Load	—	—	—
Transverse Load	1.75	4.38	2.62
Vertical Load..	.50	1.25	.75
Earth Conductor, Broken.			
Longitudinal Load	2.48	—	3.72
Transverse Load	.93	—	1.39
Vertical Load..	.28	—	.42

The longitudinal load for a conductor broken in one span represents the longitudinal component of the unbalanced tension of the conductor in the adjacent unbroken span. For an unbroken conductor the longitudinal forces on each side of the tower are balanced, and there is no resultant load.

The transverse load represents the wind pressure on the conductor and tower, and the transverse component of the conductor tension.

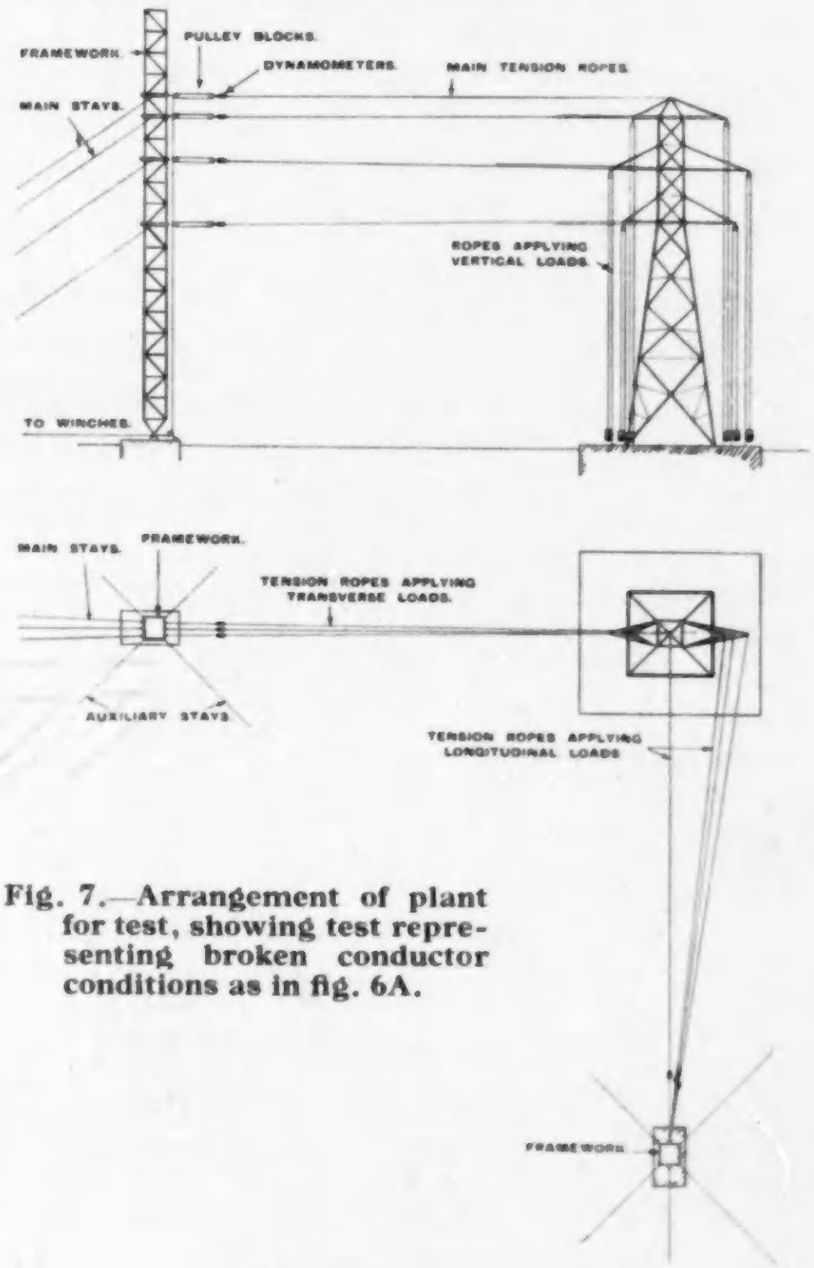


Fig. 7.—Arrangement of plant for test, showing test representing broken conductor conditions as in fig. 6A.

The vertical load represents the weight of the conductor, insulators, and ice covering them.

PROCEDURE FOR TESTING.

The test loads having been settled, the tower is arranged on the test bed and ropes are connected

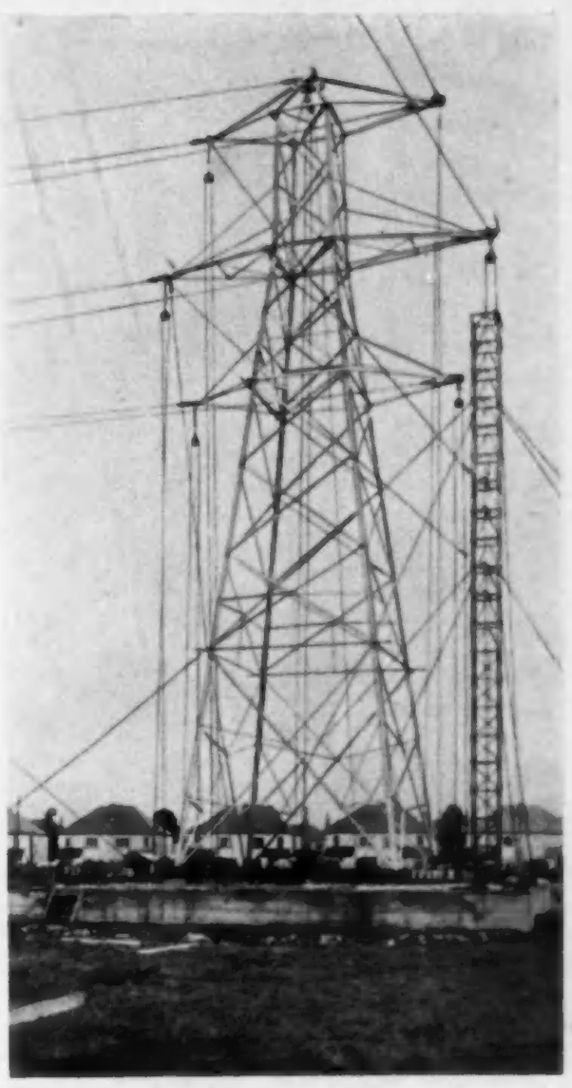


Fig. 8.—Tower under test.

to the apex and crossarm ends where loads are to be applied. Fig. 7 shows how these ropes are arranged. For accurate results, correction must now be made for any angularity of pull in a vertical or horizontal plane, for the weight of ropes and tackle, and for dynamometer calibrations.

Scales are fitted to the tower top and some of the crossarm ends so that by sighting on to the scales through fixed telescopes fitted with hair lines the deflection of the tower when loaded may be obtained.

When ready to begin the test, the operator has before him under each dynamometer gauge the correct load to be applied at each point. There will be eleven such gauges for a test such as in figs. 6A, 6B, or 6C. After zero readings have been taken in the telescopes, vertical loads consisting of cast-iron weights are applied. First the transverse loads and then the longitudinal loads are taken up to their full working figure, and the deflection of the tower is ascertained. Loads are then increased in the same order by one or two steps until full test load is reached. Fig. 8 shows a tower under a test similar to that of Fig. 6B.

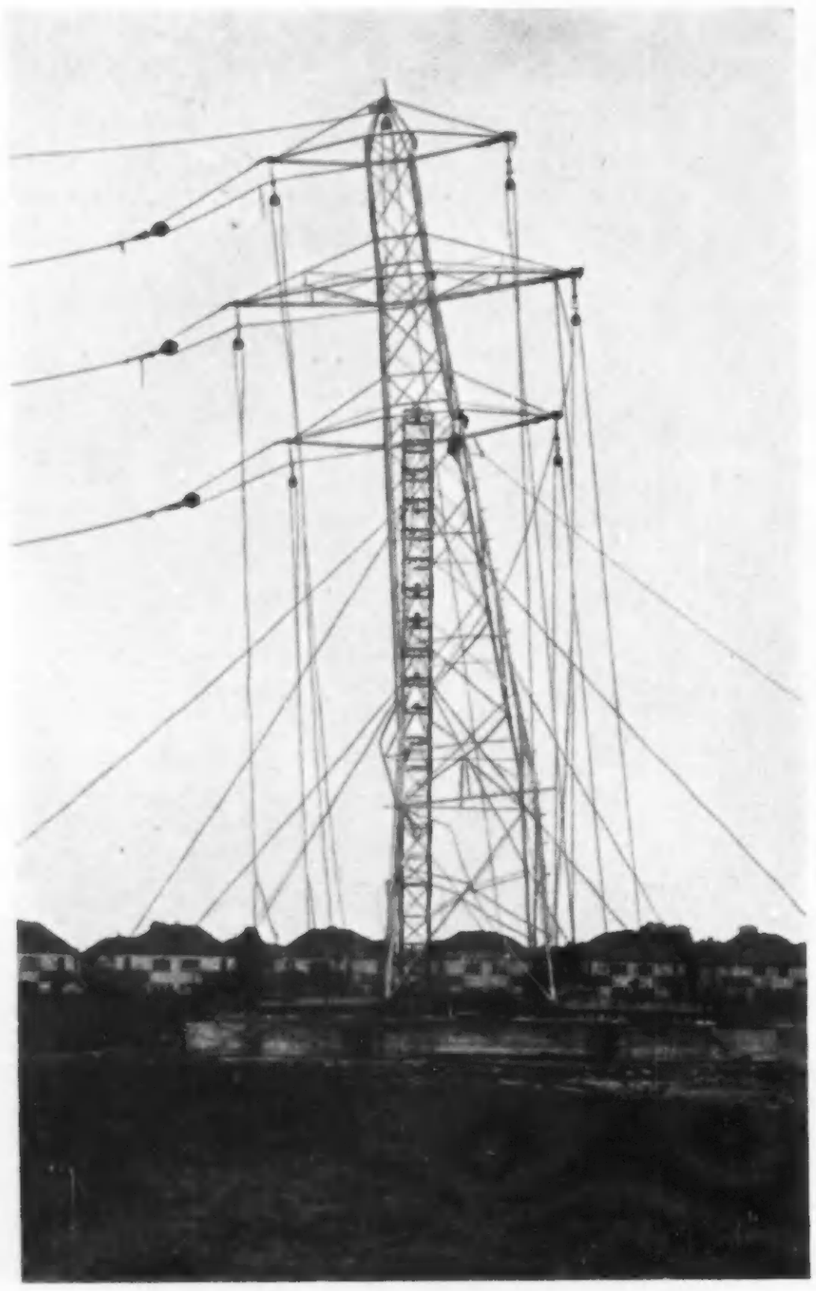


Fig. 9.—Tower failing under test.

The loads in any one direction have to be applied evenly together, as, if taken up separately, the very small deflection due to the increase of one load causes a slight decrease in the other loads, and they cannot easily be equalised. When loads are removed after a test, similar care must be taken to relieve them evenly, as it is easy to overload a crossarm should its load not be slackened with the others.

After all the acceptance tests have been carried out, it is usual to test the tower to destruction, so as to obtain some idea of what overload the tower can withstand before failure occurs. The test is usually arranged for normal conditions, in which no conductor is broken, this being the most important condition to the line engineer, and, as it involves applying a severe bending moment, the failure usually occurs by buckling of the corner legs just above a joint. Towers that have failed in this manner are shown in figs. 9 and 10. The actual mode of failure depends on the particular tower design, however, and sometimes the crossarms show signs of trouble before the tower body fails.

VALUE OF TESTS.

A well designed tower fails at between 100 per cent. and 120 per cent. of specified test load. If failure does not occur until about 20 per cent. above the specified test load has been reached, the tower is overstrong, and therefore uneconomical, as a lighter tower would suit. Thus, such a double circuit medium angle tower as that mentioned above would weigh about 11,000 lbs., whilst a straight line tower for the same line would weigh about half as much. If a lighter design of straight line tower could be made which, while quite strong enough to withstand the specified loads, would be, say, 100 lbs. lighter, a saving of about 2 per cent of the total weight would result. On a long line employing 500 of these towers such a reduction in weight represents a saving of over £500.

There is therefore a great temptation for the designer to keep down the weight of the towers. Now it has already been pointed out that the design of a tower involves a choice of empirical data, and if undue optimism is allowed to colour this choice, the result may be disastrous. Such a possibility can be avoided by using the most reliable data available and then verifying the result by such full scale tests as those described above. In this way only is it possible to produce the most economical structure consistent with assured safety and reliability.

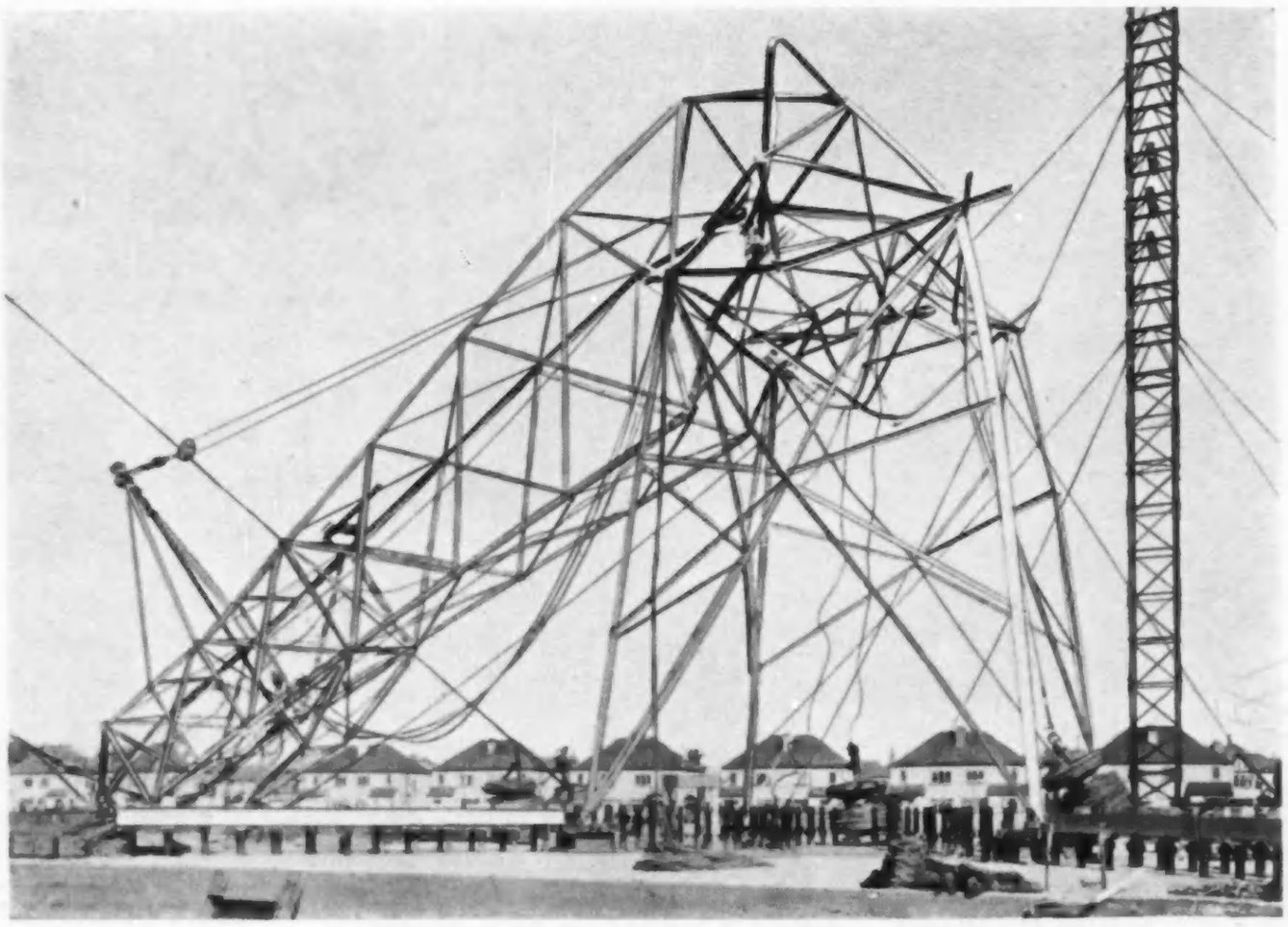


Fig. 10.—Tower after being tested to destruction.

The Remote Control of Selective Switches in Automatic Telephony.

By CHARLES W. WILMAN, A.M.I.E.E.
G.E.C. Telephone Works.

The rapid development of automatic telephony and its adaptation to increasingly severe operating conditions, have emphasized the importance of studying the characteristics of electro magnetic mechanism controlled from a distance.

In this article the author considers some of the difficulties encountered and describes the results of tests carried out on apparatus designed to overcome them.

THE basis of automatic telephone systems is the operation, by remote control from a subscriber's telephone, of selective switches situated at a central point known as the exchange. In recent years there has been an increasing tendency to extend the range of this control over longer and more difficult lines and, in order to obtain the best results from the apparatus available, it has become necessary to make a detailed study of existing conditions. It is therefore proposed, first to outline the fundamental principles of automatic telephony and, subsequently, to describe in greater detail some of the problems which arise in practice and the manner in which they are solved, with special reference to the apparatus used.

SPEAKING CIRCUITS.

Because of their liability to interference, speaking circuits consisting of a single wire with an earth return were discarded in the early days of manual telephony and replaced by two-wire metallic circuits. Economic conditions preclude the use of more line wires in an automatic system than are necessary for the speaking circuit, and although early automatic systems (so called three-wire systems) made use of an earth connection in addition to the two wires to assist in the control of the switches, modern two-wire systems effect the whole of the control over the speaking lines.

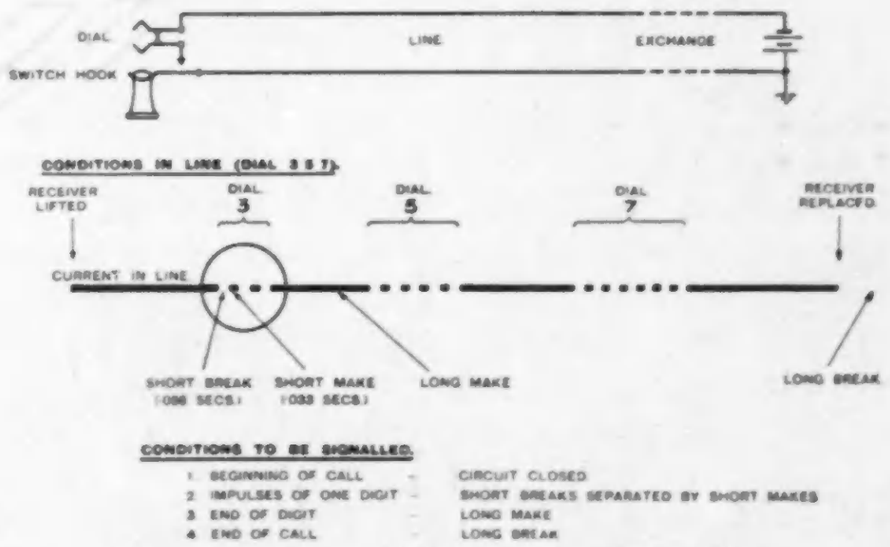


Fig. 1.—Line conditions during impulsing.

IMPULSING.

Various methods of transmitting the necessary selective signals over the line have been proposed. That universally employed is the periodical interruption of the loop circuit at the telephone, the number of interruptions depending upon the selection to be made. Electromagnetic apparatus at the exchange responds to the current impulses produced by the interruptions. The advantages of this method of control are :—

(1) Within the limits of its working range, the selection is independent of line resistance, insulation and battery voltage.
(2) The only additional apparatus required at the subscriber's station is a device for interrupting the loop circuit any number of times at will.
(3) The method of control lends itself to use in modern common battery systems in which current is fed to the subscribers' telephones from a central battery at the exchange.

In order to allow a simple form of interrupter, or dial, to be employed, and to reduce the total number of interruptions necessary to make a given selection, the interruptions are divided into a series of trains. The number of impulses in a train does not exceed ten and corresponds to one digit of the wanted number or to a numerical equivalent of one letter of an exchange name.

Fig. 1 shows these conditions in a simple impulsing circuit comprising a dial and a switch hook at the subscriber's telephone and a source of current at the exchange. The conditions in the line when the number 357 is dialled are shown graphically. Current begins to flow when the receiver is lifted and the circuit is broken three times for the first digit, five for the second and seven for the third. The circuit then remains closed during the conversation period and is finally broken when the receiver is replaced.

Clearly, the exchange apparatus must be able to distinguish between :—

(*a*) the short interruption which indicates one impulse of a train and the long interruption which indicates the end of the connection.

(*b*) the short closure between two interruptions in the same train and the long closure between two digits.

Some method of timing the duration of the "make" and "break" periods is therefore necessary.

The impulses are received upon an electro-magnetic pawl- and ratchet-driven switch. This may be one of the switches actually used for extending the connection, but if these switches are not adapted for direct control, or if the switching is not arranged upon a decimal basis, it may take the form of an auxiliary register which afterwards controls the selective switches themselves.

RELAYS.

Owing to the comparatively heavy current required, it is not practicable to operate switch magnets directly over the line wires, and a suitable relay must be interposed. In any case, it is undesirable to allow current to flow through the magnet windings during the conversation period.

By the addition of further relays, the necessary differentiation between the long and short "breaks" and the long and short "makes" already referred to, may be made.

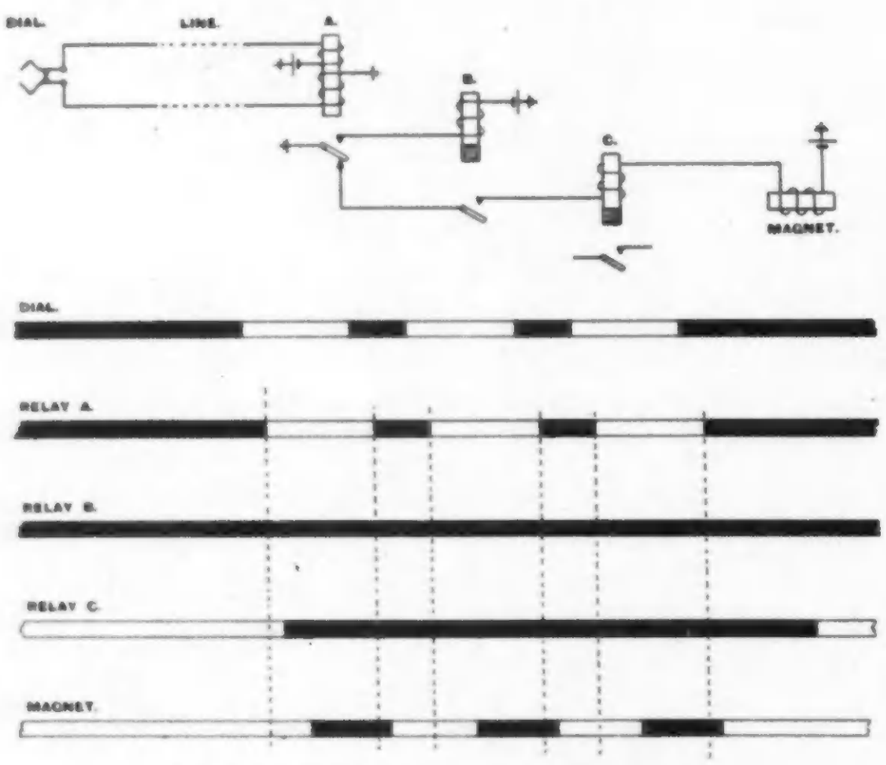


Fig. 2.—Relay and magnet circuits.

It is well known that the addition of a closed winding, or copper tube, to a relay has the effect of lengthening its operating and releasing times. This is due to the induced currents circulating in the closed path and tending to delay the growth or decay of the magnetic flux. A slow relay of this kind forms a convenient means of measuring a short period of time.

A simple dialling circuit is shown in fig. 2 and is suitable for carrying out tests on impulsing relays. When the receiver is lifted, the switch hook (not shown) closes the line circuit and relay A operates at the exchange. The positive and negative poles of the exchange battery are represented by the usual earth and battery conventions. Relay A closes a circuit for relay B, and this relay operates. Relay B, which, as indicated by its shaded end, is provided with a copper tube to render it slow to release, prepares a circuit for the switch magnet and relay C.

When the subscriber dials, relay A falls away at each impulse but relay B, being slow to release, remains stationary. Each time relay A falls away a circuit is closed for the switch magnet and relay C in series. The magnet responds to the impulses and the switch makes the appropriate number of steps.

Relay C operates in series with the magnet and, being slow to release, remains operated for the whole of the digit. It falls away during the long make period between digits, thus distinguishing between short and long makes. Similarly, relay B falls away during the long break period following the replacement of the receiver, thus distinguishing between short and long breaks. These conditions are represented graphically below the circuit, the solid parts of the lines representing the periods during which the relays and magnet are operated.

The switches available will respond satisfactorily at ten steps per second and a dialling rate of ten impulses per second has been standardized, the time of an impulse being considered as that of a break and the following make. Similarly, the ratio of break to make to be produced by the dial has been fixed at 2 : 1, giving a break period of .066 second and a make period of .033 second. In practice, dials should be kept within the limits of 9 and 11 impulses per second and the break period between 0.63 and 0.70 of the whole. To provide a margin of safety, the exchange apparatus is tested to respond correctly at rates between 7 and 14 impulses per second.

DISTORTION.

It will be noted from fig. 2 that relay A does not fall away instantaneously when the line circuit is broken ; nor does it operate instantaneously when the circuit is closed. This effect is independent of the time which is actually taken by the relay to move from one position to the other (transit time). It is of the order of 2 or 3 milli-seconds only and can usually be neglected. In an inductive circuit the current does not rise instantaneously to its ultimate value and the value of the current after a time t is given by the Helmholtz equation :—

$$i = \frac{E}{R}\left(1 - \epsilon^{-\frac{Rt}{L}}\right)$$

where R is the resistance and L the inductance of the

circuit. The growth of the flux is therefore gradual. Similarly, if the relay is released by short circuiting, the current dies away gradually. In the present case, release is obtained by opening the circuit and the delay in the decay of flux is due to induced currents in the core itself.

If the times of operation and release are the same, the duration of the impulses relayed to relays B and C and the magnet will not be affected, although the impulses will lag slightly behind those in the line. If, however, the times of operation and release are not the same, the impulses will be distorted.

Thus, in fig. 3, the first line shows the conditions in the line circuit with a correctly adjusted dial. The second line shows the relative timing of a relay having equal operating and releasing times, the impulses being displaced but not distorted.

The third line refers to a relay which takes longer to operate than to release, and it will be seen that the break periods are lengthened at the expense of the make periods. The limit of allowable distortion in this direction is reached when either the magnet fails to release between successive impulses, or the B relay fails to hold on the shortened impulses. In practice it has been found that the B relay is the limiting factor and falls on the reception of a long train of distorted impulses.

Similarly, the fourth line refers to a relay which takes longer to release than to operate. In this case, the make periods are lengthened at the expense of the breaks. The limiting factor is either the magnet, which fails to operate when the time during which the relay is down becomes too short, or the C relay, which may not hold on reception of the shortened impulses.

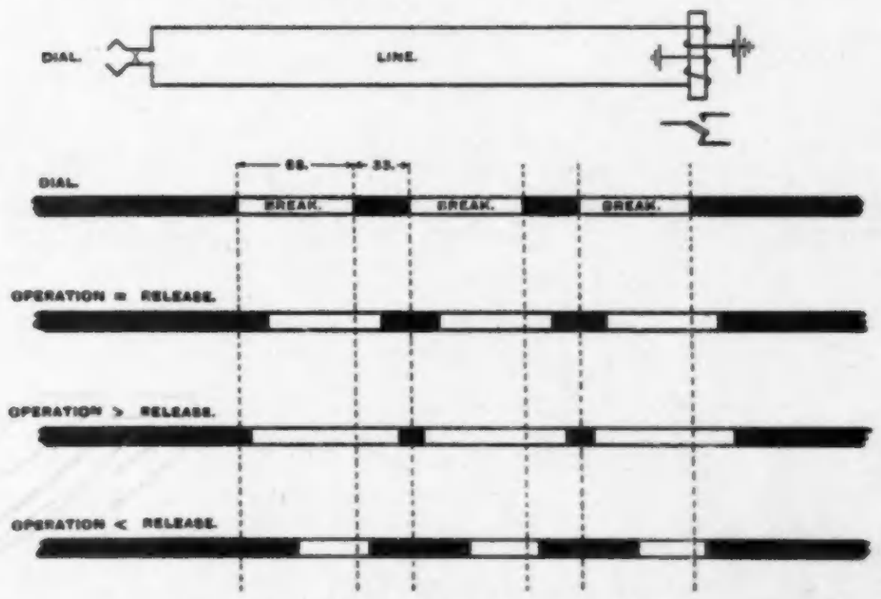


Fig. 3.—Distortion of impulses.

It may be noted here that when the *rate* of impulsing is increased the limiting factor is the magnet, which may fail to respond to the shortened impulse. On the other hand, the magnet will not fail owing to a decrease in the dialling rate. The slow relays now form the limiting factor and may fall in the lengthened periods during which they receive no current.

LINE RESISTANCE AND INSULATION.

It would be easy to provide a relay having equal operating and releasing times if the conditions under which it worked were constant. But economic considerations at the exchange prevent the allocation of a separate impulse-receiving circuit to each subscriber's line, and the lines may vary greatly in resistance and insulation. Other variable factors are the voltage of the exchange battery, which must

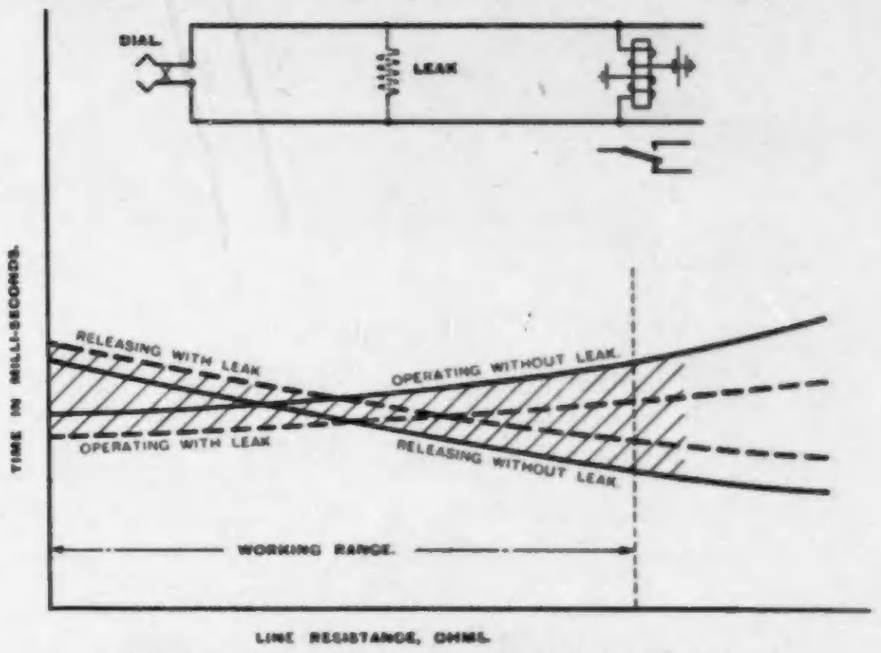


Fig. 4.—Operating and releasing curves.

be allowed a reasonable working range, and the time for which the relay is impressed with current at each impulse, which affects the releasing time and depends upon the accuracy in speed and ratio of the dial in use.

The effects of resistance in the line are to delay the operation and reduce the time of release of the impulsing relay, since it causes the current to grow more slowly and to a smaller steady value. If the times of operation and release are plotted against line resistance, curves such as those shown by the solid lines in fig. 4 are obtained. Clearly, the condition for no distortion (equal operating and releasing times) can exist only for one line resistance, indicated by the point at which the curves cross.

The effects of a leak between the lines are to shorten the operating time (owing to a small initial flux at the moment the dial contacts close) and to increase the releasing time (owing to the slightly higher ultimate value reached by the current and to the slugging effect of the leak when the dial contacts open). Leaks from one or both lines to earth are roughly equivalent to a leak of twice the value across the lines, since current due to an earth leak passes through only one winding of the impulsing relay. The effect of a leak on the operating and releasing times is shown by the dotted lines in fig. 4. It is convenient to draw these curves to represent the maximum leak which will be allowed on the lines in practice.

The shaded area on the drawing is a measure of the distortion produced. The worst operating conditions occur on a short line with a leak and on a

long line with no leak, and the impulsing relay should be designed so that failure is equally unlikely at both ends of the line range required. The best relay for the purpose is clearly one for which the curves approach as near the horizontal as possible.

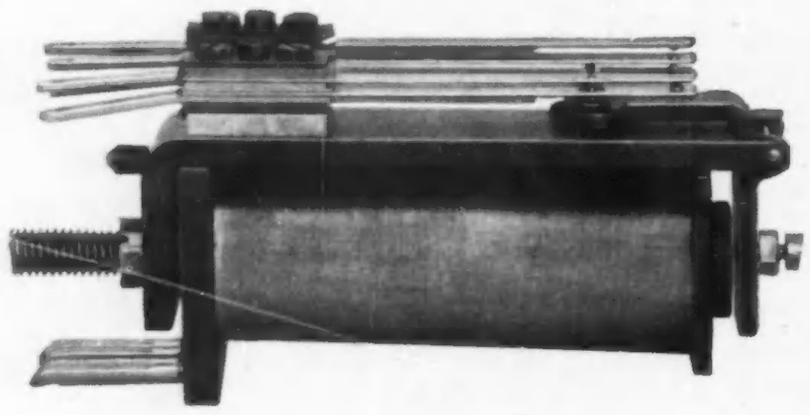


Fig. 5.—Impulsing relay.

TYPES OF RELAY.

In fig. 5 is shown a relay which has given good results under these conditions. The armature is suspended on a pin-type hinge which ensures a good impulsing action. It has an adjustable residual screw. The contact-springs have dome-shaped contacts and are provided with buffers to locate the springs and prevent bouncing of the contacts.

For the slow relays, the type shown in fig. 6 is used. A knife-edge suspension for the armature ensures a magnetic circuit of low reluctance, thus assisting in delaying the decay of flux. For a similar reason, the armature in the operated position is very near to the core, three small residual pins being used. The sleeve of high-conductivity copper is underneath the winding.

LINE AND LEAK OSCILLOGRAMS.

A copy of oscillograms showing the rise and fall of the line current during impulsing is shown in fig. 7. The first broken line represents the make and break of the dial contacts, adjusted to the correct ratio of 2 : 1. Below this is an oscillogram of the line current with negligible line resistance, followed by a broken line showing the operation of the impulsing relay. Under these conditions, the break period repeated by the relay was 63 milli-seconds, a decrease of about four milli-seconds from that in the line.

The next curve represents the current when the line resistance is increased to 1500Ω, the effect on the relay is seen in the broken line below. The break period has been increased to 76 milli-seconds, or nine milli-seconds more than that given by the dial.

For the last curve, a leak of 20,000Ω was connected across the line, the line resistance being zero. The distortion is now in the opposite direction, the break period being 59 milli-seconds. The depression in the current curve, which occurs a

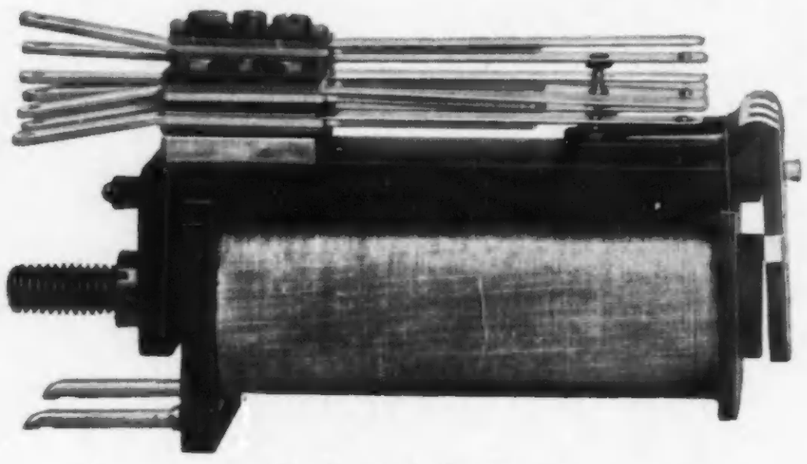


Fig. 6.—Slow relay.

short time after the closure of the circuit, is due to the operation of the relay armature, which decreases the reluctance and increases the inductance of the relay. It is noticeable to a smaller extent in the other curves.

CAPACITY.

If a line has capacity, a charging current flows for a time after the circuit is opened at the dial contacts,

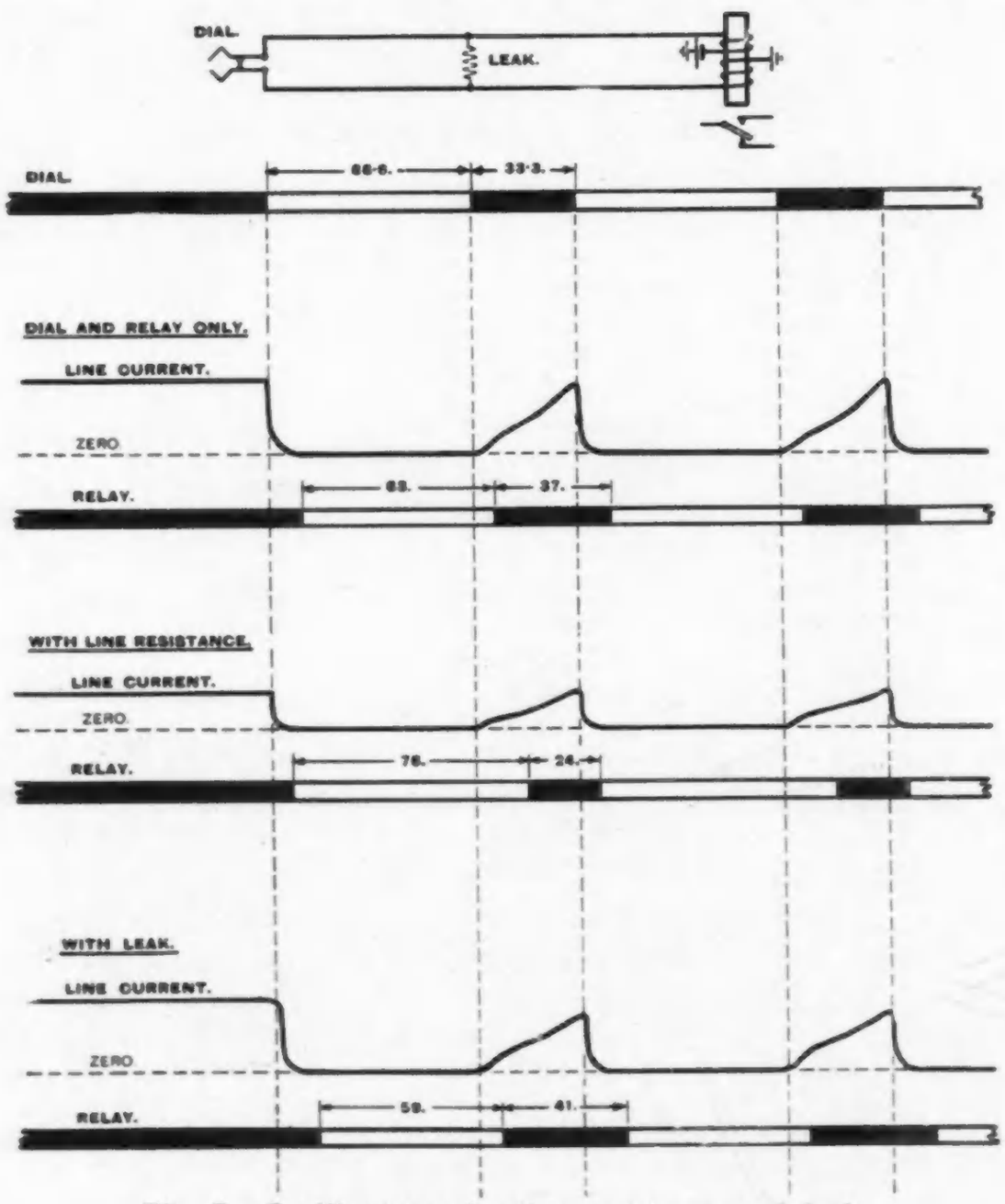


Fig. 7.—Oscillograms for line resistance and leak.

and the release of the impulsing relay is delayed. The operation is also delayed owing to the extra time required for the current in the relay windings to grow when the contacts are closed. For capacities above about 0.25 $\mu F.$, the delay on release is found to be greater than that on operation, and the make period is therefore increased. Capacity, like leakance, therefore, tends to improve the dialling characteristics of high resistance lines.

In practice, with ordinary subscribers' circuits, the most important capacity to be considered is the condenser in the telephone circuit. Its primary object is to maintain a circuit for the alternating current used to ring the bell on an incoming call when the receiver is on the hook and the direct current calling loop is broken.

If the impulsing contacts of the dial completely break the line circuit, the induced voltage on the line, due to the rapid collapse of flux in the impulse relay at the exchange, may reach dangerously high values. If the circuit is arranged so that the condenser is connected across the dial contacts, this tendency is greatly reduced. The condenser alone, however, tends to cause pitting of the contacts. The circuit is therefore arranged so that the condenser is in series with one winding of the induction coil and this arrangement gives good impulsing (the line range being actually better than normal), a satisfactory reduction of the induced voltage, and freedom from contact pitting.

TELEPHONE CIRCUIT.

The impulsing circuit manufactured for the British Post Office is shown in fig. 8. When the

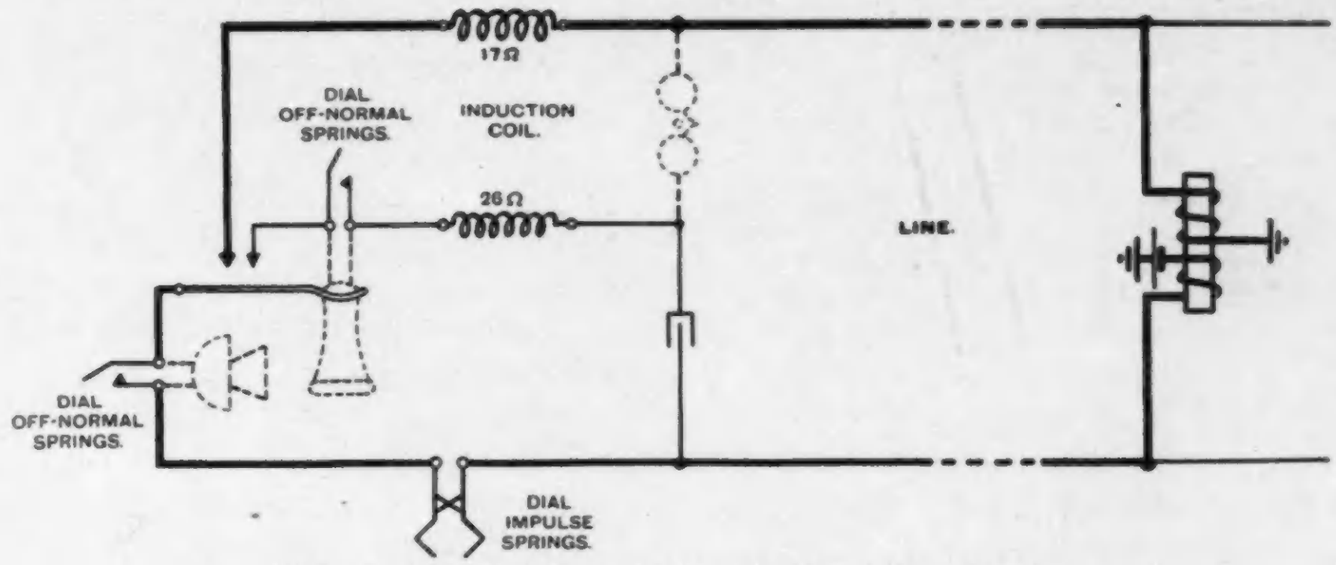


Fig. 8.—Impulsing conditions in telephone circuit.

receiver is lifted, the dial impulse springs are connected in series with the line loop, the transmitter, and one winding of the induction coil. The transmitter, however, is short circuited during impulsing by "off-normal" contacts on the dial, which are closed while impulses are being sent.

Across the impulse springs are connected the condenser, the other winding of the induction coil, and the receiver, in series. The receiver, like the transmitter, is short circuited during impulsing by off-normal contacts. Those parts of the circuit that are not concerned with the impulsing circuit are shown dotted.

It is not intended in this article to discuss the mechanical features of the dial employed but fig. 9 is included to illustrate its general appearance and the position of the impulsing and off-normal contacts. Views of the front and rear are shown on the left and right respectively. The impulsing contacts are operated by the toothed cam during the return movement of the finger plate, and the off-normal contacts by the arm seen in the centre.

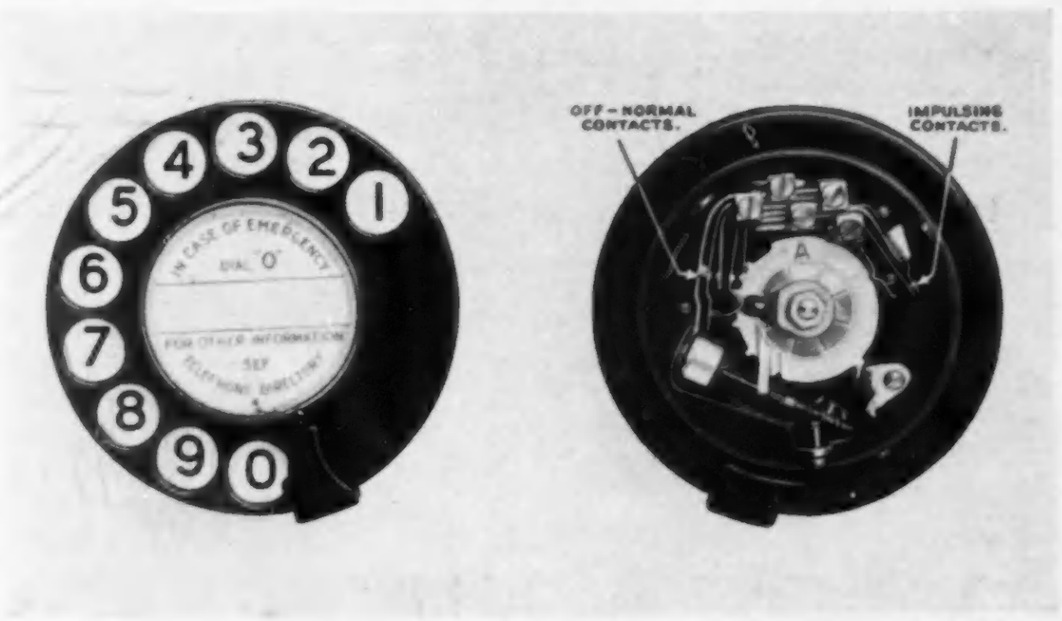


Fig. 9.—Standard subscriber's dial.

OSCILLOGRAMS WITH TELEPHONE CIRCUIT.

In fig. 10 are shown copies of oscillograms for the two cases in which the above circuit is used on a short and long line. In both cases the effect of the capacity in delaying the rise and fall of current in the line is well marked. The length of the break period on the short line is 59 milli-seconds, which, as might be expected, is slightly less than the similar condition in fig. 7 where the dial

only was tested. On the long line, the break period is 68 milli-seconds, which shows considerably less distortion than the corresponding curve in fig. 7.

Where a number of telephones are connected to the same line, as in the case of party line and extension instruments, the additional condensers cause a further increase in the make period. Their

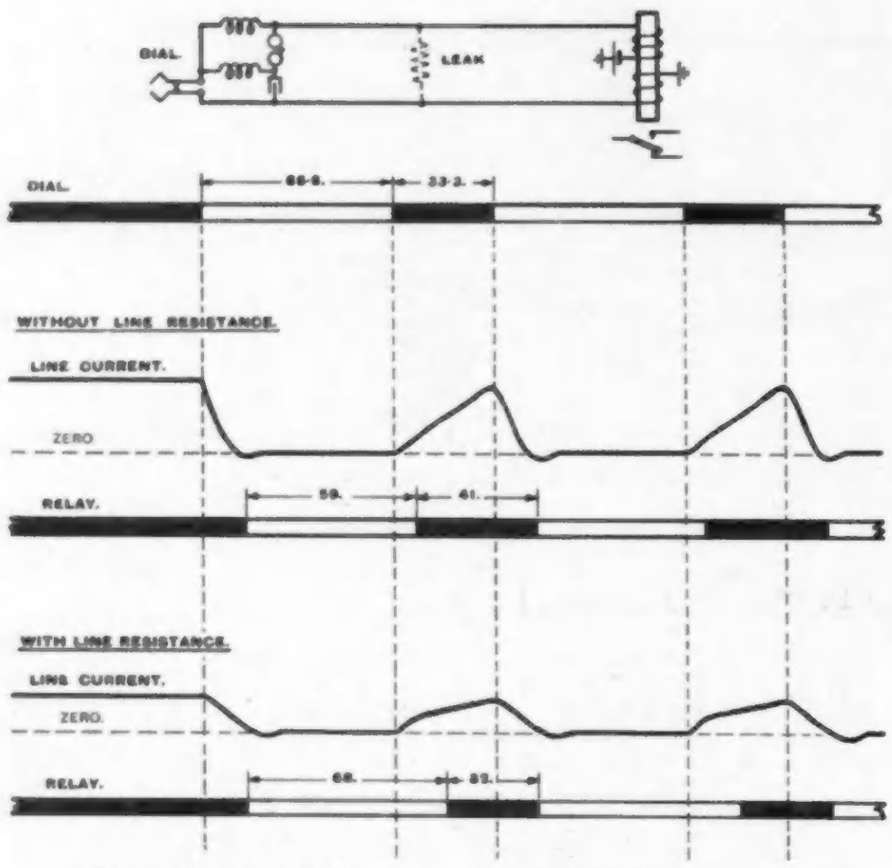


Fig. 10.—Oscillograms with complete telephone circuit.

effect is comparatively small since, when the instruments are not in use, the condensers are in series with the high impedance of the bell windings and the induction coil is not in circuit.

EXTENSION OF CALLS OVER JUNCTIONS.

It has so far been assumed that the magnet of the step-by-step switch which is to receive the impulses can be operated directly by the impulsing relay controlled over the calling line. This is not practicable when a call is extended through one exchange to another and it becomes necessary for the impulsing relay at the first exchange to repeat the impulses received over the calling line to a similar relay at the second exchange.

These conditions are illustrated in outline in fig. 11. Below the circuit diagram are three broken lines which, assuming that under the line and voltage conditions which obtain, both relays take longer to operate than to release, represent the operation of the dial and the two impulsing relays. The distortion under these conditions is cumulative and places a severe limit on the number of serially related junctions over which impulses can be repeated. Several methods of correcting the distortion have been proposed but they have not been generally adopted. It is not possible to adjust the relays permanently so that the second corrects the distortion introduced by the first, because either must be capable of working with other relays under conditions which may result in distortion of the opposite kind.

Large systems are sometimes so arranged that the dial operates switches at the originating exchange only, those at further exchanges being set by impulses generated at the first exchange. By this method distortion caused by inaccuracies in the dials themselves is not added to that introduced by the impulsing relays.

Since reliable earth connections are always available at exchange premises, impulsing over a single wire and earth return is satisfactory for signalling from one exchange to another when differences in earth potential can be neglected. This method is adopted in certain cases of impulsing

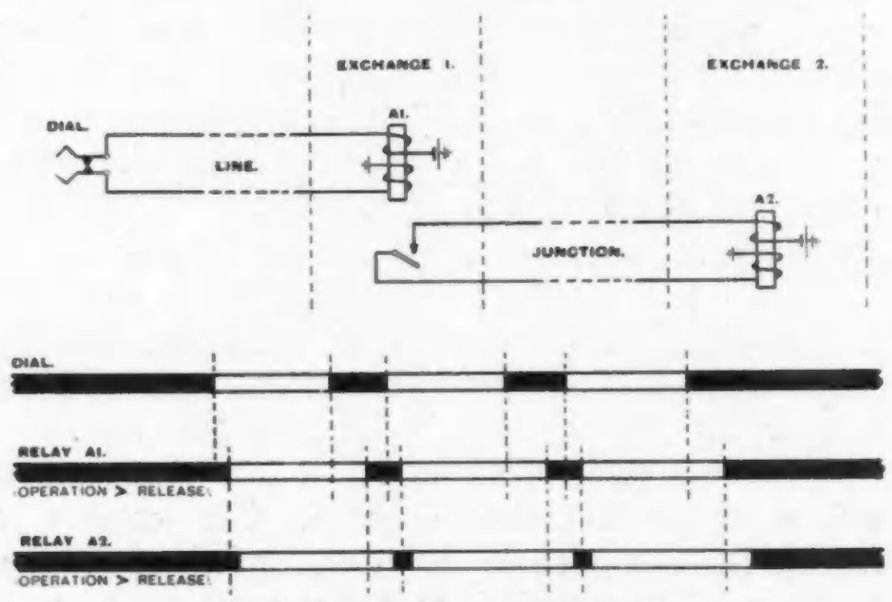


Fig. 11.—Junction conditions.

from manual to automatic exchanges where limitations imposed by existing manual circuits prohibit two-wire dialling. An advantage is the reduced resistance owing to the use of the single line. A still further reduction in resistance, making it possible to impulse over very long circuits, is obtained if the two line wires are used in parallel with an earth return.

The Manufacture of Oil-Filled Cables.

By R. E. HORLEY, A.M.I.E.E., A.M.A.I.E.E.
Works Manager, Eastleigh Factory, Pirelli-General Cable Works Ltd.

This is the first of a series of three articles dealing with oil-filled cables. In the present description the author outlines the various manufacturing processes, emphasizing those which differ radically from the production of ordinary cable.

The second and third articles will describe respectively the oil feeding accessories and the method of installing the cable.

THE rapidly increasing use of electricity for industrial and domestic purposes has produced such a change in the problem of distribution that it can no longer be met by the comparatively low voltage networks which have served their purpose for many years. It seems but a short while ago that 33 kV cables were first used to interconnect neighbouring power stations, and to transmit power in bulk to sub-stations on the fringe of the distribution area. Due to the increased voltage, trouble occurred with these cables and it seemed that a critical point had been reached beyond which new methods of manufacture and design were necessary to meet the increase in working stress.

The introduction of the "H" cable and the triple-single core cable marked another step in the march of progress and made 33 kV cable transmission safe.

By this time, however, engineers were beginning to doubt whether the voltage increase was sufficient, or whether a pressure of 66 kV, whilst involving little extra risk, did not offer substantial advantages, not only in the amount of power which could be transmitted, but also in the saving of congestion in the streets. Meanwhile, research work in the Pirelli laboratories had shown that a complete solution of all the problems associated with cable dielectric was not to be found in the conventional method of manufacture, and a new type of cable was gradually being developed with very promising results.

THE INTRODUCTION OF THE OIL-FILLED CABLE.

The introduction of the Pirelli oil-filled cable raised the voltage at which it is practicable to transmit power by underground cables to 220 kV. So far, no commercial lines have been installed for such a high pressure, but experimental lines of oil-filled cables for this voltage have been laid down in Italy and have proved satisfactory. It is interesting to note that the first underground cables to be placed in commercial service at a working pressure of 132 kV were of this type, and, since the date of their installation in America in 1927, they have given uninterrupted service.

A short time ago Pirelli oil-filled cables for a working pressure of 66 kV were laid between Battersea and Fulham, and Fulham and Hammersmith for the Central Electricity Board and in April of this year the installation of 132 kV double circuit oil-filled cable lines between Eltham and Deptford was started. The sectional area of these cables is .20 sq. in. and the double circuit lines will be capable of transmitting 150,000 kVA continuously.

FEATURES OF THE OIL-FILLED CABLE.

The manufacture of oil-filled cables possesses certain features which differ radically from those of the normal type with which engineers are familiar. It is felt, therefore, that a brief description of the more important manufacturing processes will prove of interest.

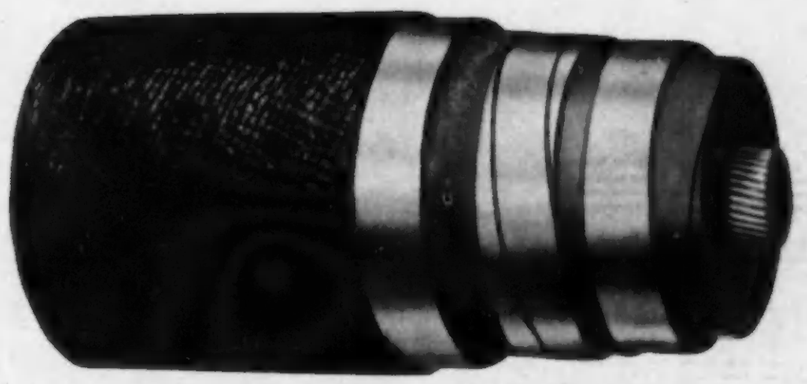


Fig. 1.—Section of oil-filled cable.

In the oil-filled cable, of which fig. 1 shows a section, it is not only possible to ensure a very thorough impregnation of the cable insulation, but, in addition, this impregnation can be maintained under all working conditions. To achieve these results, the conductors are stranded around a cylindrical helix,* leaving a cavity at the centre of the core.† This cavity is completely filled with oil which is maintained within certain predetermined pressure limits by means of special reservoirs and pressure tanks.** To enable the necessary pressure limits within the cable to be observed, an oil-filled cable installation is divided into sections, each fed from an external source of

* Pirelli Patent No. 257,894.
† Pirelli Patent Nos. 114, 414, and 178,662.
** Pirelli Patent Nos. 251,670, 255,034, and 267,059.

oil and separated from succeeding sections by means of stop joints through which the electrical connections are carried, but which shut off the oil from that in adjacent sections.

of larger cables. Steel is used in large cables in order to give the necessary internal support against external pressure. Fig. 2 shows a machine for constructing the spiral, the metal strip being lapped on

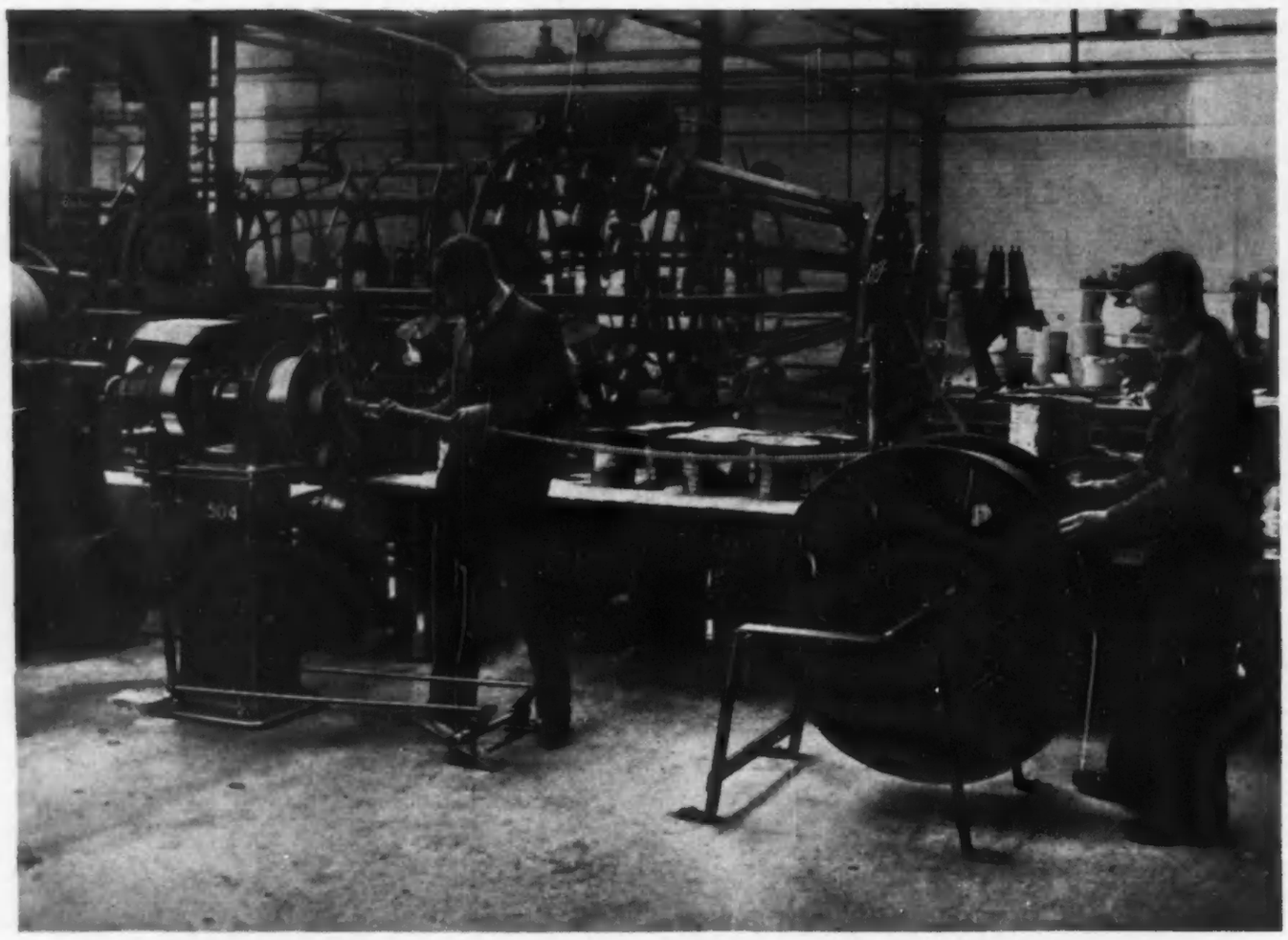


Fig. 2.—Manufacture of steel spiral round which conductor is stranded.

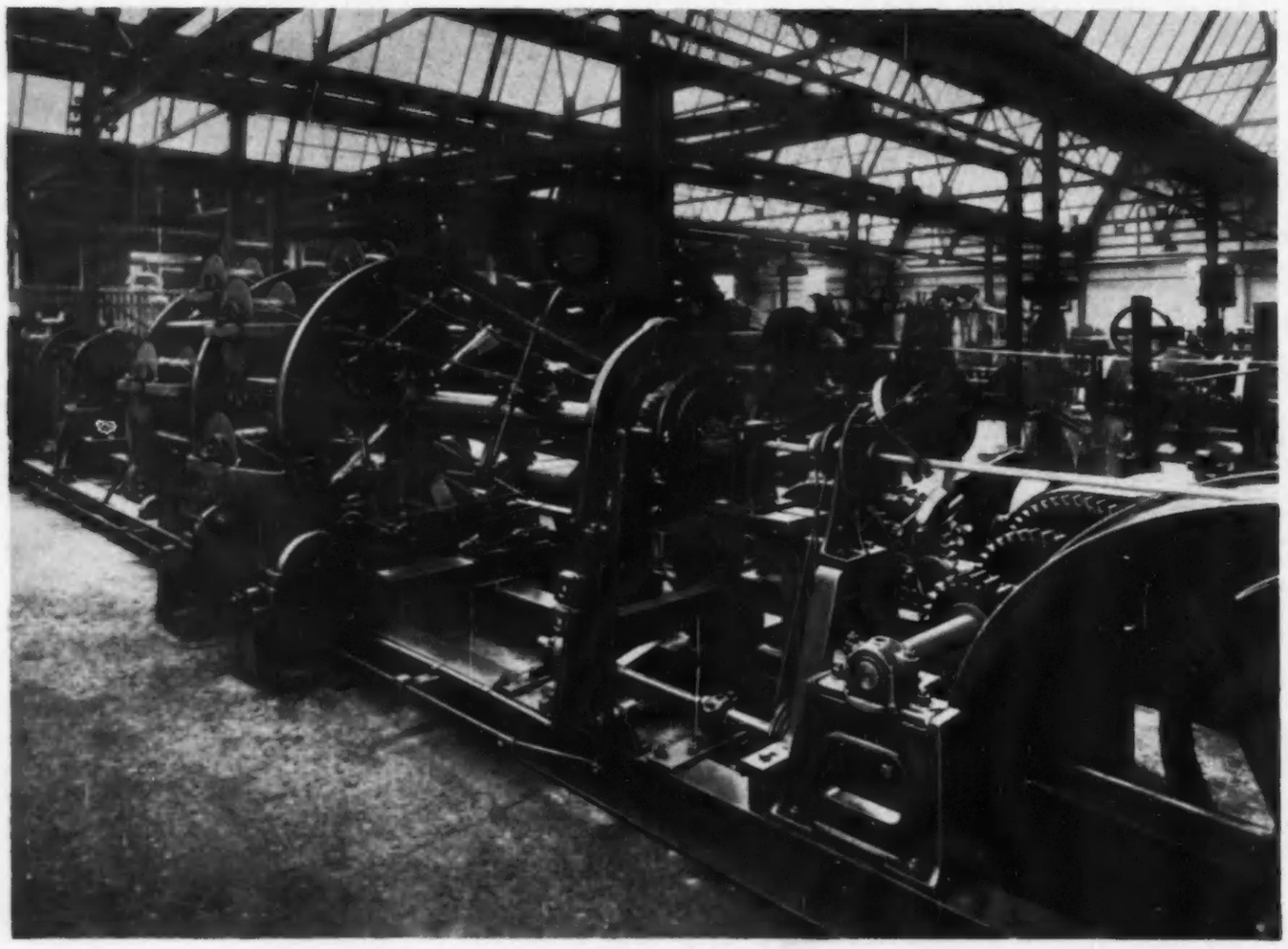


Fig. 3.—Stranding conductor round spiral.

FORMING THE CORE.

The spiral which contains the central cavity of the cable, and around which the conductors are stranded, is made from a plain narrow metal strip—copper in the case of the smaller cables and steel in the case

to a mandril which is threaded with a groove having the same pitch as it is desired to give the spiral. The steel used is 40-ton bright oil finished. The conductor is then stranded over the spiral in the normal way as shown in fig. 3. In order to assist

the passage of oil from the cavity to the insulation (in cables where the conductor consists of more than one layer of wires) alternate wires in a layer of the strand are deformed by passing them through a machine which consists of two rollers, one plain and one notched. This however, is not necessary in single layer strands.

Fig. 4.—25-head paper lapping machine.

PAPER INSULATION.

The paper used for building up the dielectric of high-tension cables is to-day almost invariably of the wood pulp type, from which the undesirable constituents, such as lignin, are removed by chemical process.

Upon arrival at the factory the paper is very carefully tested to see that no trace of the chemicals used in their manufacture is still present and that they conform with the purchasing specification for the type required. An average value of breaking strength for paper used for oil-filled cable is 7/8,000 lbs. per square inch longitudinally and 3,500 lbs. per square inch transversely, while the elongation corresponding to a pull equal to the breaking force is from 2 to 2.5 per cent. longitudinally, and 4 to 4.5 per cent. transversely. A very important property of cable paper is its porosity and the method of grading paper by its porosity, due to Emanueli*, is of great importance in building up the dielectric of cables for very high working pressures.

Fig. 5.—Lowering paper-covered core into drying tank for preliminary drying.

For oil-filled cables, the use of paper having a high impermeability is possible because the oil employed for impregnating the cable is of low viscosity. This ensures a dielectric having the maximum possible strength.

The paper is cut into strips and is lapped around the conductor by machines, one of which is shown in fig. 4. The core is drawn through the machines by a capstan and during its passage a number of heads, containing rolls of paper rotating at a constant speed, wind paper tapes helically round the conductor. Each head rotates in a direction opposite to that of the head preceding it, the turns of the first layers over-lapping while the final layers are applied with a small gap between each turn. Fig. 4 shows a machine having twenty-five paper lapping heads, used for building up the dielectric of oil-filled cables.

The thickness of paper varies from 3½ to 7½

* Pirelli Patent No. 181,097.

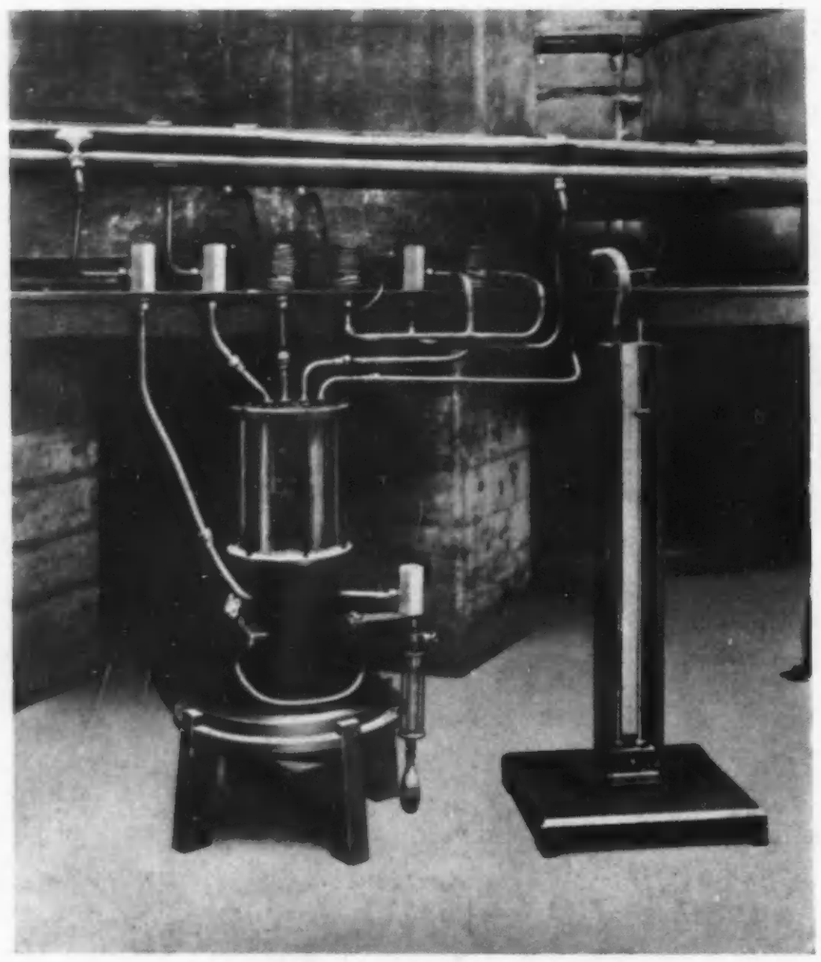


Fig. 6.—Impregnating bottle.

mils. In normal type super-tension cables it is not safe to allow a stress of more than about 5,000 volts per m/m, but in the oil-filled cable, owing to the better impregnation obtained and maintained, it is quite safe to allow a stress of 8,000 volts per m/m so that the thickness of dielectric necessary is considerably reduced.

LEAD SHEATHING AND FIRST IMPREGNATION.

The core, after emerging from the paper lapping machine, is wound on to a steel cylinder and lowered into a drying oven (fig. 5) which is then hermetically sealed and exhausted to a vacuum of approximately 29 ins. of mercury. A preliminary drying is carried out by steam heating the tank, after which the cable is passed to the lead press where it receives its first lead sheath. This procedure is a radical departure from the manufacture of normal type cables, which are impregnated after drying and then lead sheathed. Following the lead sheathing process, a pipe connection is sweated to one end of the cable and a combined pipe and test end connected to the other end. The cable is placed in a steam heated tank and connected through an arrangement of vacuum tight valves to a glass cylinder, called an "impregnating bottle," fig. 6. By means of this valve system, it is possible to connect either one or both ends of the cable to the vacuum pump through the bottle, while a mercury "U" tube manometer may be connected to the bottle to measure the degree of vacuum. By leaving a small quantity of oil in the bottle the extraction of air bubbles from the cable can be watched and the progress of the operation gauged. Fig. 7 shows a battery of steam heated tanks used for the first impregnation of the cable and fig. 8 illustrates a cable tank from the side of which pipe connections are taken to the vacuum and impregnating apparatus. The special test end can be seen protruding through a packed gland in the side of the tank. A very high degree of vacuum is used and the temperature of the cable is maintained at 100° C., by means of saturated steam in contact with the cable. Tests of power factor, capacity and insulation resistance are taken until the figures show that the cable is perfectly dried. The product of insulation resistance and capacity is, in addition to the power factor, of particular value in gauging the exact electrical condition of the cable and its power factor, as this product is independent of geometrical dimensions.

It should be noted that unless the lead sheath remains perfectly sound at 100° C., the process cannot be carried out and this forms a very valuable check on what is a most important stage in the manufacture of any cable, *i.e.*, the lead sheathing process.

INSULATING OIL AND IMPREGNATION.

The insulating oil necessary for impregnating is first of all prepared by passing it through a centri-

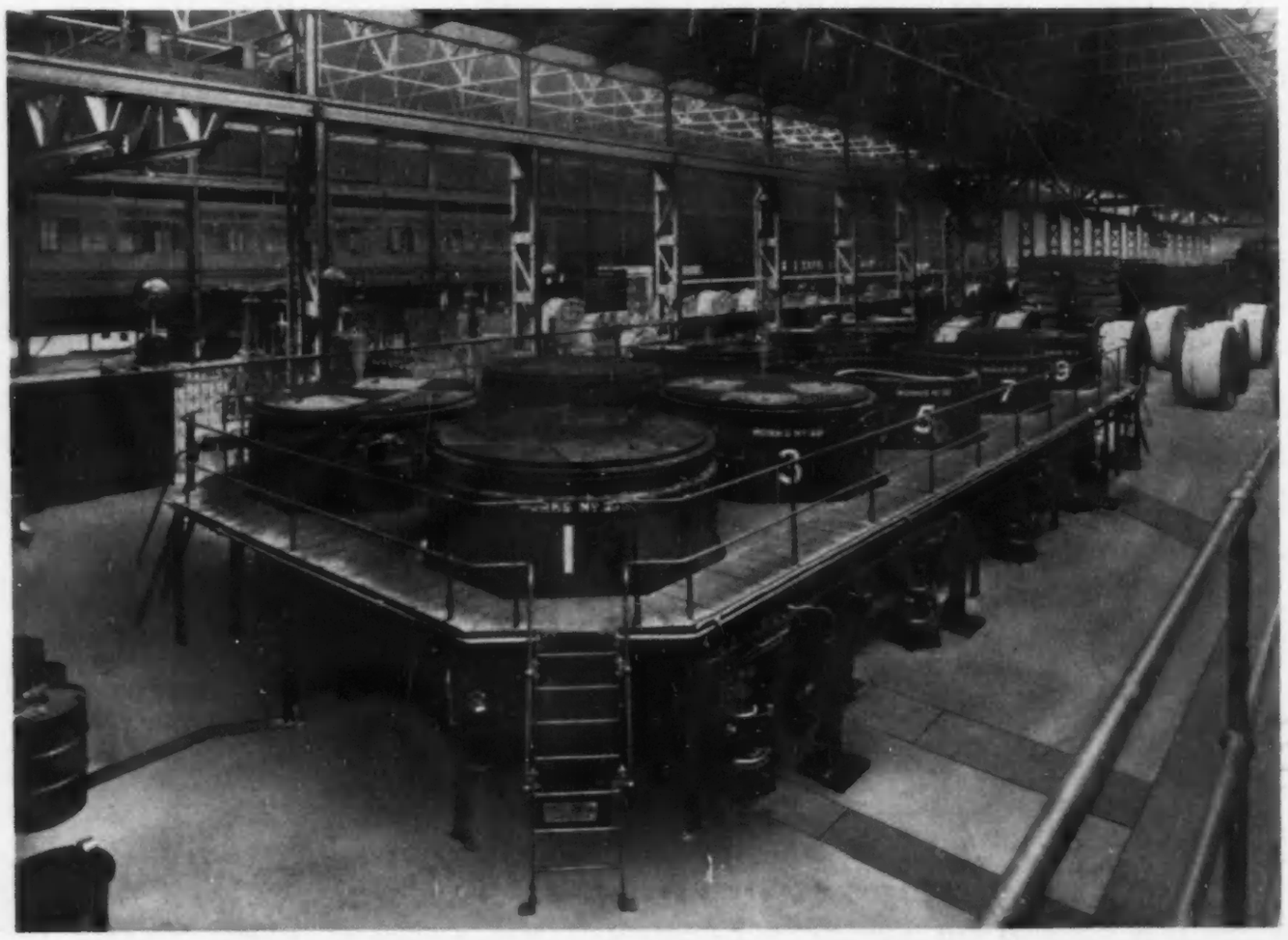


Fig. 7.—Battery of steam-heated impregnating tanks.

fugal machine, which clarifies it and removes any water which may have found its way in during transit. It is then pumped into a boiler and dried at 100° C. under vacuum. Tests are carried out for dielectric strength and, when found satisfactory, the dried oil is passed through special degasifying apparatus and pumped into a battery of flexible-walled feeding tanks installed at a height of about twenty feet to provide a flow at sufficient pressure for impregnating the cable. Fig. 9 shows a number fo drying and degasifying units.

The cable being ready for impregnation, a quantity of oil is drawn off by means of the valve system through the impregnating bottle so as to carry away any small bubbles of air contained in the connecting pipe lines.

Vacuum is maintained on one end of the cable and oil is admitted at the other end. In a period of time which can be predetermined from the length and size of the cable, oil arrives at the far end. The cable is impregnated but is still hot, so the feeding tanks are left connected after shutting off the steam and cold water is admitted to the tank. More oil is fed into the cable as it cools down.

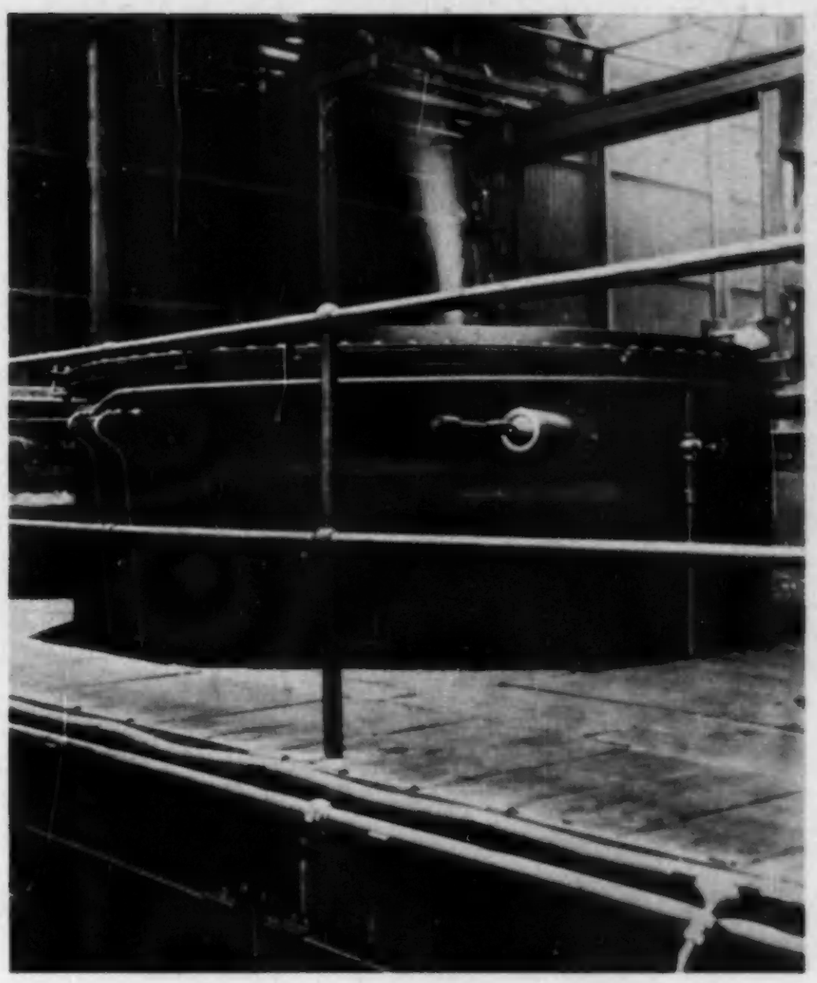


Fig. 8.—Test end of cable protruding through impregnating tank.

IMPREGNATION TEST.

The impregnation being complete, its degree of perfection is checked by means of an impregnation test made in the following way. The feeding tanks are shut off from the cable, leaving the latter full of oil at a moderate pressure which is measured by the manometer. Any small quantity of air distributed in the cable will also be compressed to the same pressure. If a small quantity of oil is drawn off from the cable the air will expand to occupy the extra volume available and its pressure will drop. This drop in pressure is indicated by the drop in pressure of the oil. Corrections have to be made for small amounts of air trapped in the impregnating bottle and these are found by making a separate impregnation test on the bottle itself. Sometimes the cable has not quite finished cooling and pressure-time readings are taken before and after withdrawal of the test volume of oil, the results being plotted on squared paper. Since the rate of cooling taken over small time intervals does not change, the true pressure difference due to the withdrawal of the oil is obtained. From the ratio of change in pressure to volume of oil withdrawn, the impregnation constant of the cable is found. This impregnation constant is very important because it has long been suspected that the power factor of a cable changes with the applied voltage, and this change has been attributed to the ionization of gas in the insulation. As a result of research on oil-filled super-tension cables, this fact has been definitely proved and it is now known

Fig. 9.—Drying and degasifying units.

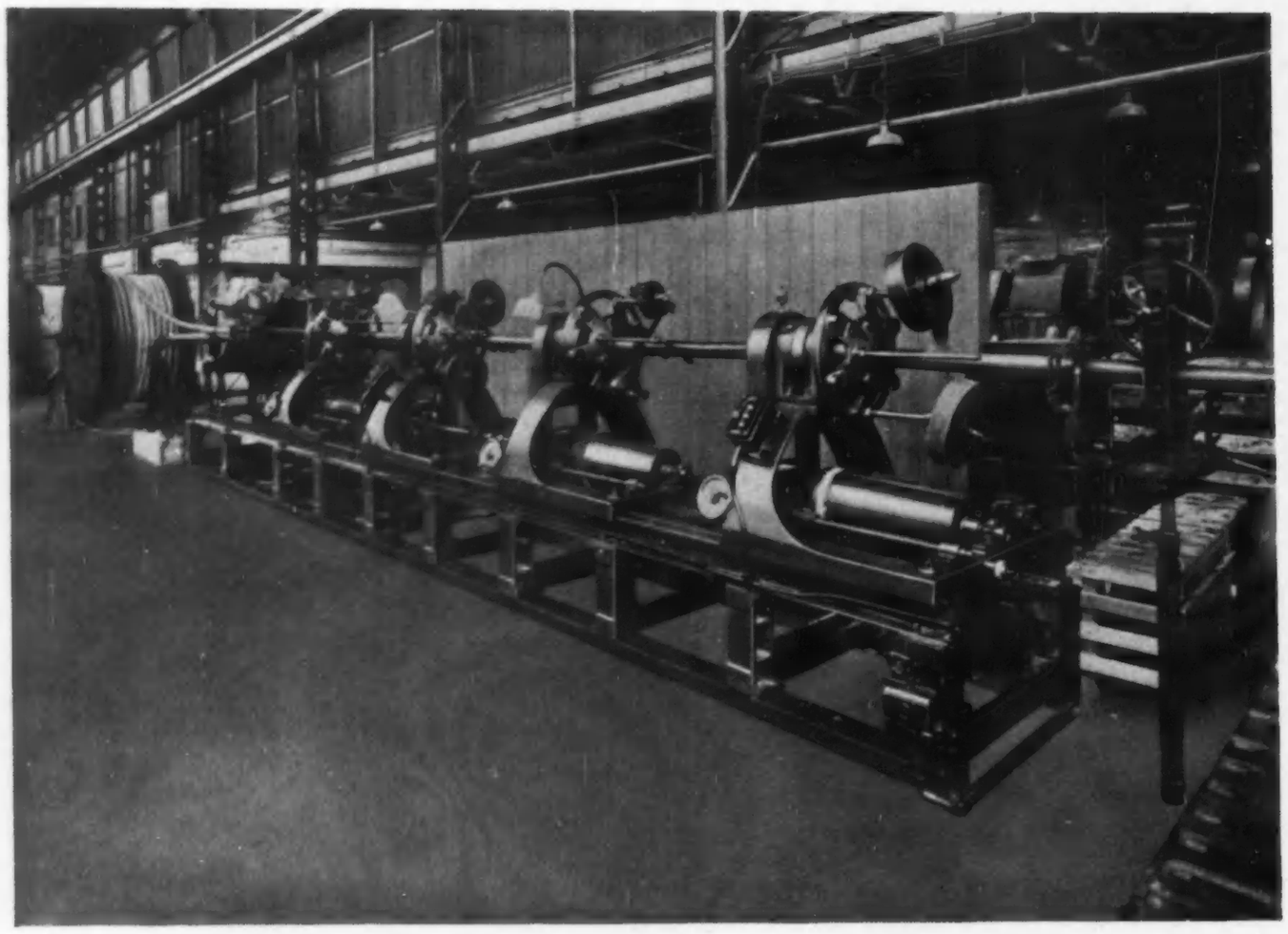


Fig. 10.—Brass tape armouring machine.

that the impregnation constant is exactly proportional to the ionization occurring in the cable. The ionization constant in the present case is taken as the change in power factor of the dielectric measured at voltages of 10 and 100 volts per mil of insulation thickness of the cable. It is thus possible to know, as soon as the cable is impregnated, whether the electrical tests will be satisfactory, and to re-impregnate the cable if the desired standard is not reached. Owing to the close check on all the preceding operations, however, re-impregnation is very seldom necessary.

LABORATORY TESTS.

Before the next stage in the manufacture of the cable is begun, it is sent to the laboratory where dielectric strength, power factor and the usual routine tests are made, special oil-filled testing ends being fitted for this purpose. Fig. 11 shows typical power factor voltage curves for 66 kV oil-filled cable tested at 15° C. immediately after manufacture and after seven heat cycles up to 100°C., each of twenty-four hours duration. It will be observed that, as would be expected, the cable is absolutely unaffected, showing that impregnation is still perfect. For purposes of comparison, typical curves of power factor voltage variation for normal type super-tension cables are shown in the same illustration.

ARMOURING AND APPLICATION OF SECOND LEAD SHEATH.

When the cable has passed the electrical tests, the oil is blown out of the centre of the cable by means of dry carbon dioxide under pressure. It is

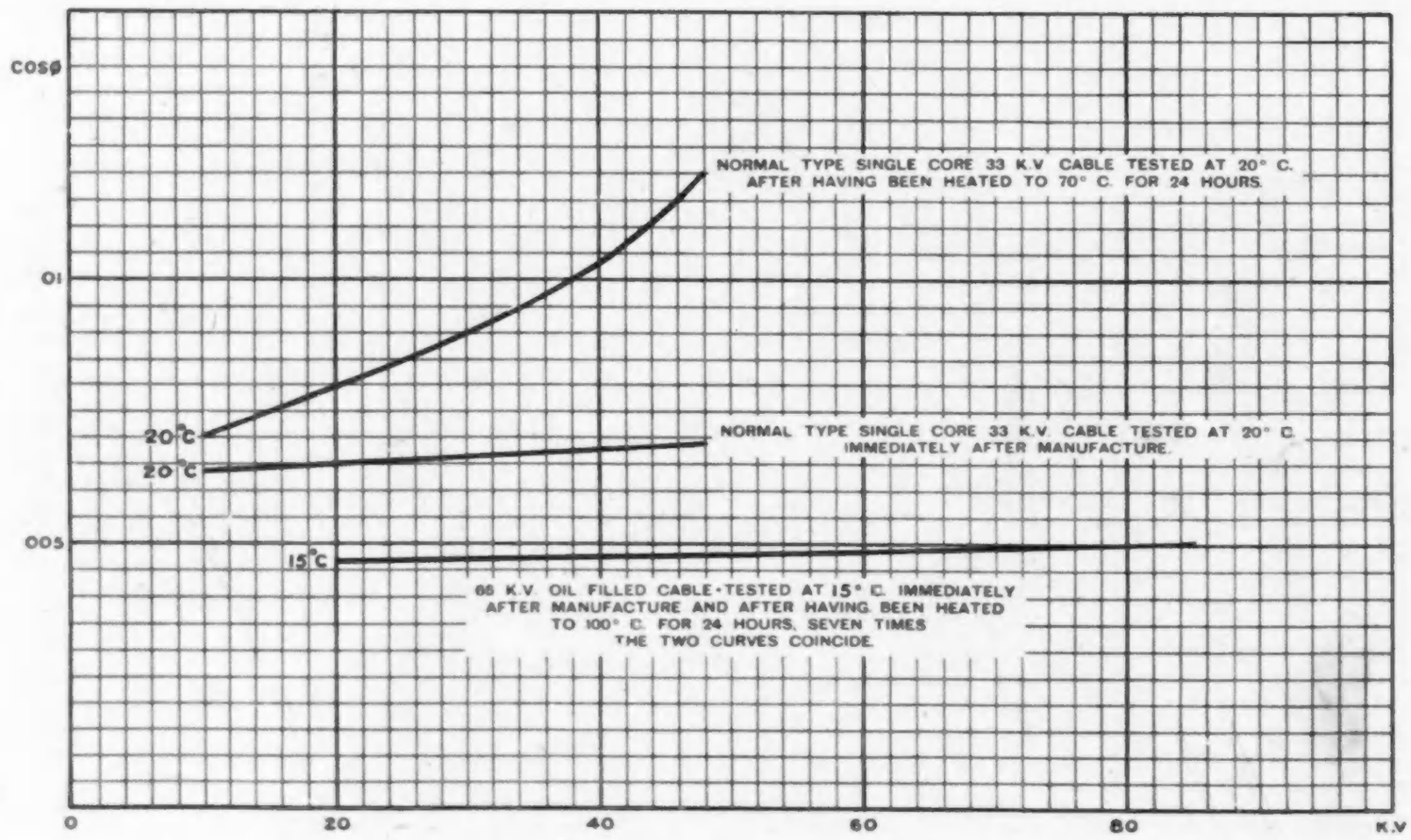

COSΦ
01
005
0
20
40
60
80
K.V
NORMAL TYPE SINGLE CORE 33 K.V CABLE TESTED AT 20° C. AFTER HAVING BEEN HEATED TO 70° C. FOR 24 HOURS.
NORMAL TYPE SINGLE CORE 33 K.V. CABLE TESTED AT 20° C. IMMEDIATELY AFTER MANUFACTURE.
20°C
20°C
15°C
66 K.V. OIL FILLED CABLE TESTED AT 15° C. IMMEDIATELY AFTER MANUFACTURE AND AFTER HAVING BEEN HEATED TO 100° C. FOR 24 HOURS, SEVEN TIMES
THE TWO CURVES COINCIDE.

Fig. 11.—Typical power factor voltage curves for normal and oil-filled super-tension cables.

necessary to remove the oil because, after the cable is brass tape armoured, it is again lead sheathed and the increase in temperature caused by the lead sheathing would increase the oil pressure to a dangerous extent. Moreover, it is not convenient to maintain feeding tank connections during the subsequent manufacturing operations. After removing the oil the cable is passed to the armouring machines, fig. 10, where it passes through a bath of insulating compound and is lapped around with a cloth tape having a suitable overlap. An armouring of hard brass tape is then applied in the ordinary manner with a suitable gap. The insulating paper is next applied and finally a cloth tape is wound on with an overlap over the paper. All these coverings are applied in one operation.

The cable is then taken to the lead press where it receives its second lead sheath which consists of a special ternary alloy, and finally the cable is served overall with two impregnated papers and two compounded hessian tapes applied in reverse directions. After each operation, the cable is passed through a bath of preserving compound. It is then passed through a bath of ordinary compound and is limewashed.

Fig. 13.—Oil-filled cable wound on special drum, showing pressure tank partly removed.

MAINTAINANCE OF OIL PRESSURE DURING DESPATCH.

Every length of oil-filled cable is despatched from the factory completely filled with oil. It will be appreciated, however, that owing to temperature differences between the factory and the locality where the cable is to be laid, to bending of the cable or to slight deformation of the lead sheathing due to handling or accident, the length, though completely filled with oil when despatched from the factory would not necessarily be in this condition after its arrival upon site. Provision therefore must be made to keep the length air-tight and subject to a pressure of oil maintained from the outside. This is effected by incorporating in the drum a tank filled

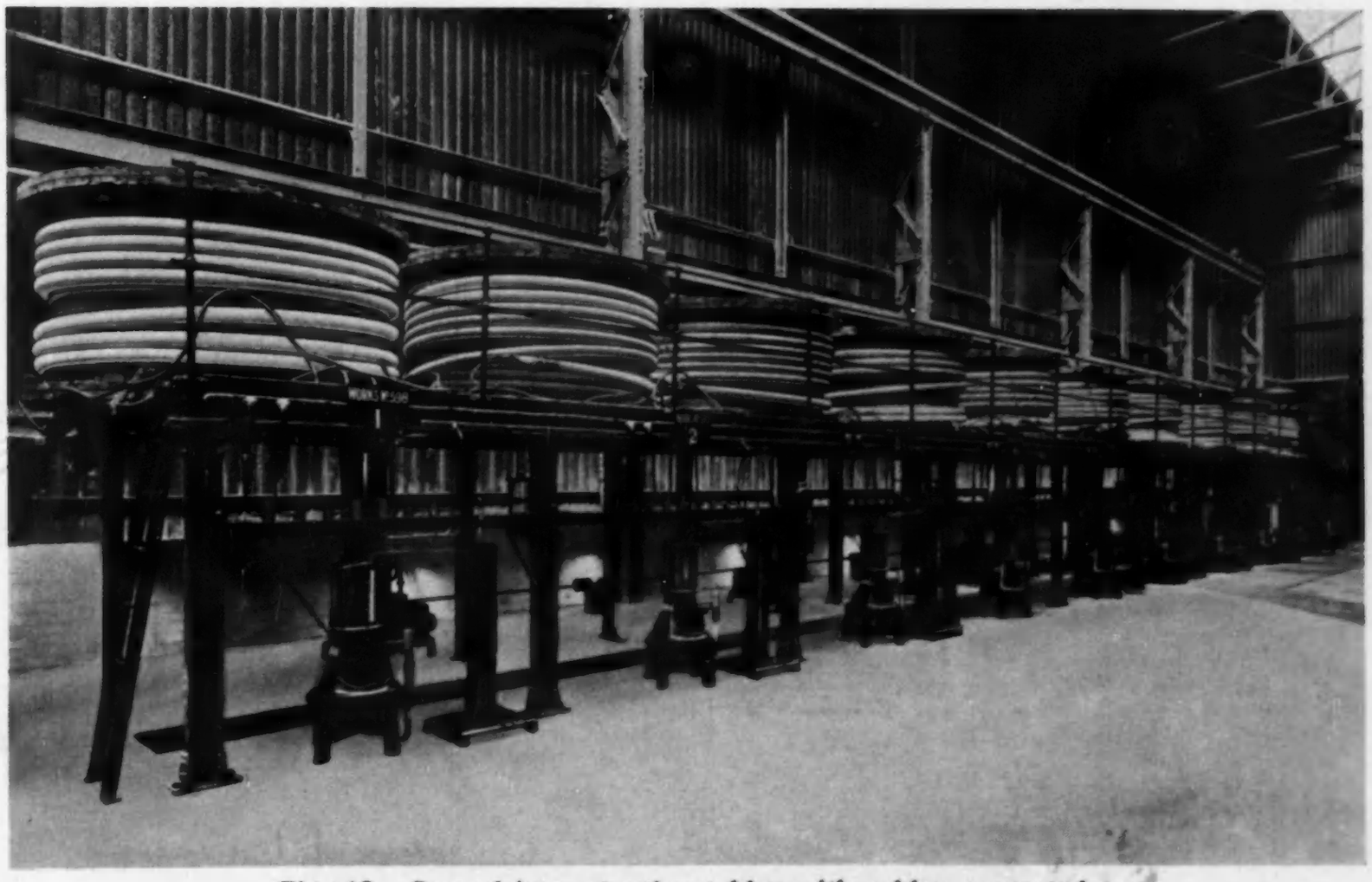


Fig. 12.—Second impregnation tables with cables connected.

with oil under pressure, and connected to the cable length.*

FINAL IMPREGNATION.

The cable length, after it has been served and finally limewashed, is wound on to one of the special drums described above, and its ends are fitted with brass caps, each having two removable gastight plugs. Both ends of the cable are then connected to the impregnating apparatus, while one end is also connected to a carbon dioxide cylinder, three of the gastight plugs being removed to enable the connections to be made. Fig. 12, shows the second impregnation tables with the cables connected to their respective impregnating units. The cable is now subjected, by means of vacuum pumps and the carbon dioxide cylinder, to alternate cycles of vacuum and treatment with carbon dioxide. This removes the oil which for any reason may have remained in the central passage, and also ensures that the final residual atmosphere left after the last vacuum treatment shall consist of carbon dioxide, which is highly soluble in the impregnating oil.

The valve connecting the cable with the impregnating oil is then opened and the cable is completely filled with oil. An impregnation test is finally carried out and this must compare favourably with the value found after first impregnation. The cable is then ready for connecting to its drum tank and disconnecting from the apparatus. In fig. 13, a length of oil-filled cable is seen wound on to one of these special drums and connected to the small pressure tank, which is partly removed to show the connections. In this condition the cable can be despatched and during its journey can encounter climatic variations without its impregnation being affected. Further, it may be stored indefinitely and remain in perfect condition.

* Pirelli Patent No. 304,912.

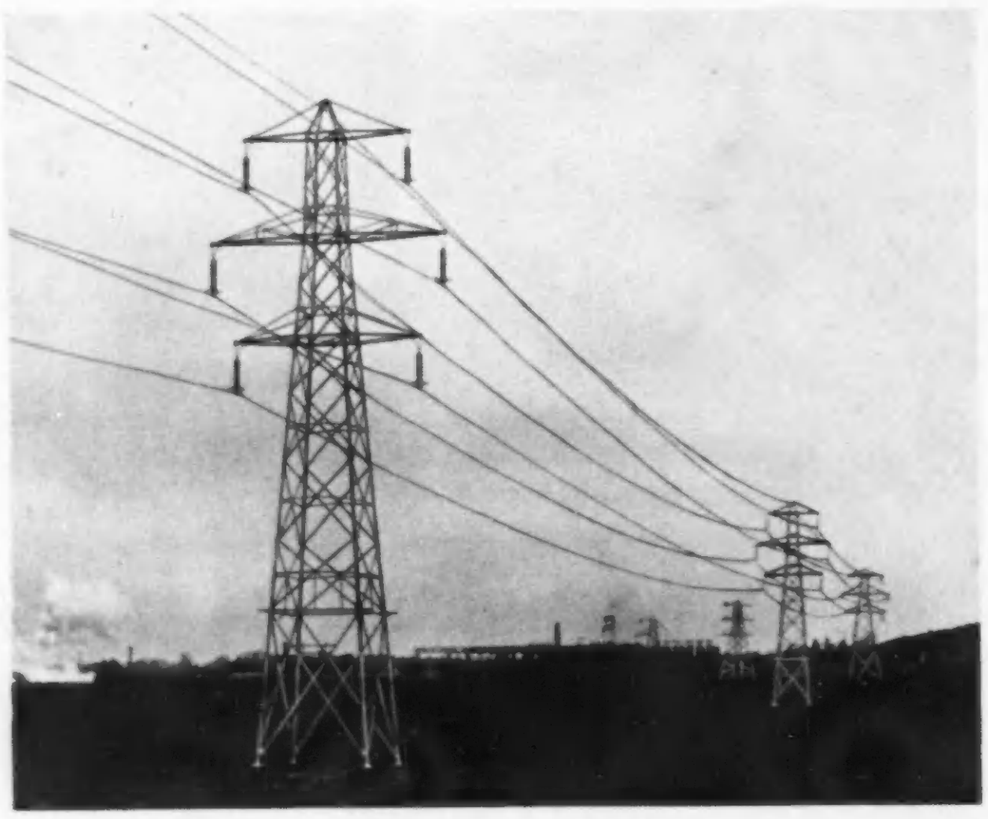
Luton-Bedford 132 kV Overhead Transmission Line.

THE illustration shows the 132 kV double circuit overhead transmission line from Luton to Bedford, approaching Bedford outdoor sub-station. This primary line is a section of the South East England Electricity Scheme and was put into operation on the 29th May, 1930.

It consists of six steel cored aluminium line conductors and one over-running steel cored aluminium earth conductor. Each line conductor consists of 30 aluminium strands and seven steel strands, and has an overall diameter of .77 in., with a copper equivalent of .175 sq. in. cross section. The earth conductor is composed of 12 aluminium and seven steel strands, having an overall diameter of .55 in., and an equivalent copper area of .068 sq. in.

Suspension insulators, having nine discs in series, 10 ins. in diameter, are used on the straight line towers, the insulators being fitted with arcing horns at the crossarm ends and with rings at the conductor ends.

The galvanised lattice steel towers vary from 72 to 98 ft. in height and are 14 to 25 ft. square at the base. The normal span is 900 ft. with a conductor sag of 22 ft.



Automatic Sub-station Equipment at Southend-on-Sea.

By W. R. COX, B.E., A.M.I.E.E.
Switchgear Dept., Witton Engineering Works of The General Electric Co., Ltd.

THE successful operation of automatic electrical apparatus and the large economies obtained by its use, have brought about the rapid extension of automatically controlled sub-stations, interesting examples of which are afforded in the Southend-on-Sea district. The Southend authorities have to administer one of the largest seaside areas in the country with a population, mainly residential, estimated at 125,000. The area comprises such well known resorts as Southend-on-Sea, Westcliffe-on-Sea, Leigh-on-Sea and Thorpe Bay. As is usual in non-industrial districts, the load is chiefly for lighting and tramway traction. Power was formerly obtained from steam and Diesel engine driven D.C. generators at the main power station in London Road, Southend, and from auxiliary stations at Leigh-on-Sea and Thorpe Bay, but a high tension bulk supply is now taken from the County of London Electricity Supply Company's power station at Barking, the original plant being retained to supplement this supply during peak loads.

A map of the district is shown in fig. 1 and illustrates the system of e.h.t. distribution throughout the area. The positions of the London Road, Leigh and Thorpe Bay generating stations are clearly indicated, these stations being connected by duplicate e.h.t. feeders. The map also shows other interconnecting feeders, forming ring mains which are either partially completed or about to be installed.

Fig. 1.—Southend-on-Sea area showing system of e.h.t. distribution. The three main generating stations are indicated by the larger black circles.

AUTOMATIC EQUIPMENTS.

The automatic equipments, with which this description is concerned, are installed in the two sub-stations at Leigh and Thorpe Bay and function either automatically, being governed by the rise and fall of load on the local networks, or by remote supervisory control from London Road generating station.

The Leigh sub-station contains two 1,000 kW, 750 r.p.m. automatic and remote controlled rotary converters, while, at Thorpe Bay, two similar machines, but each of 750 kW capacity and 1,000 r.p.m., have been installed. With the exception of the supervisory control panels at London Road, each of the two sub-stations contains all the apparatus necessary for the automatic control of its own rotary converters.

It may be mentioned that a 1,150 kW, 750 r.p.m. hand-operated rotary converter is also installed at London Road.

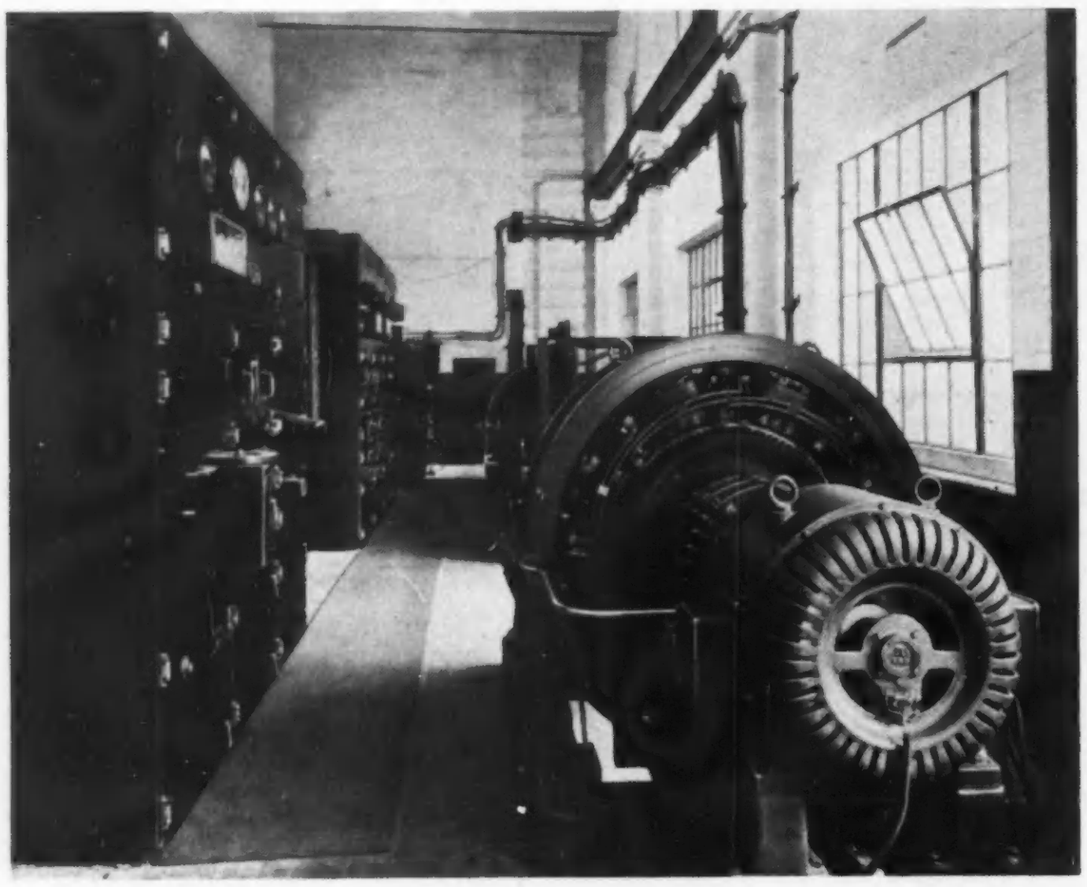


Fig. 2.—Leigh-on-Sea sub-station, which contains two 1,000 kW automatic rotary converters.

BULK SUPPLY.

The 11,000-volt, 3-phase, 50-cycle bulk supply is received at the Leigh sub-station where part is converted to direct current, while the remainder is transmitted to the London Road and Thorpe Bay stations by duplicate feeders.

At present, power is bought on a maximum demand basis and, as far as possible, the converting equipment is being operated to carry the basic load, being supplemented during peak loads by the Diesel engine and steam sets.

LOCAL SERVICES.

As previously mentioned, the load in the area may be divided into two parts as follows :—

(*a*) 3-wire lighting at 480/520 volts.

(*b*) 2-wire Tramway traction at 510/570 volts.

All the rotary converters are connected so that they can supply either the 3-wire distribution or the 2-wire traction networks.

D.C. VOLTAGE RANGE.

It will be noted that the total variation of D.C. voltage required is 480/570 volts, an unusually wide range. This variation is greater than can conveniently be obtained by field adjustment, coupled with reactance in the transformers, but since the requirements for lighting and traction divide the range into approximately two equal parts, an additional set of tappings has been brought out of the l.t. side of each of the main transformers. The D.C. voltage range can thus be obtained in two parts by field adjustment.

This arrangement makes it necessary to shut down a machine to change the l.t. transformer tappings, but since a number of switching operations are necessary to change a machine over from traction service to lighting service, no inconvenience is caused.

Tappings are also provided in the usual way on the h.t. sides of the transformers to cater for variations of e.h.t. supply pressure.

REMOTE CONTROL EQUIPMENT.

The system of remote supervisory control employed at Southend enables the control and supervision of any number of points up to 24 to be carried out by means of two pilot wires only. The remote control equipment for each sub-station consists of:-

(*a*) A desk type control panel (fig. 3).

(*b*) A despatcher cabinet.

(*c*) A receiving cabinet.

(*d*) Two 50 volt nickel-iron batteries and suitable resistances for "trickle" charging from the mains.

(*e*) Two power relays for each point controlled.

(*f*) The necessary interlocks on the oil circuit breakers, D.C. circuit breakers and contactors, the positions of which are indicated at the remote control point.

Of the above items, (*a*), (*b*) and one of the batteries on item (*d*) are situated at the control station, while the remaining gear is installed in the sub-stations.

CONTROL PANEL.

The indicating lamps and the operating keys which initiate the control signals are mounted on two slate panels, one for each sub-station. For each

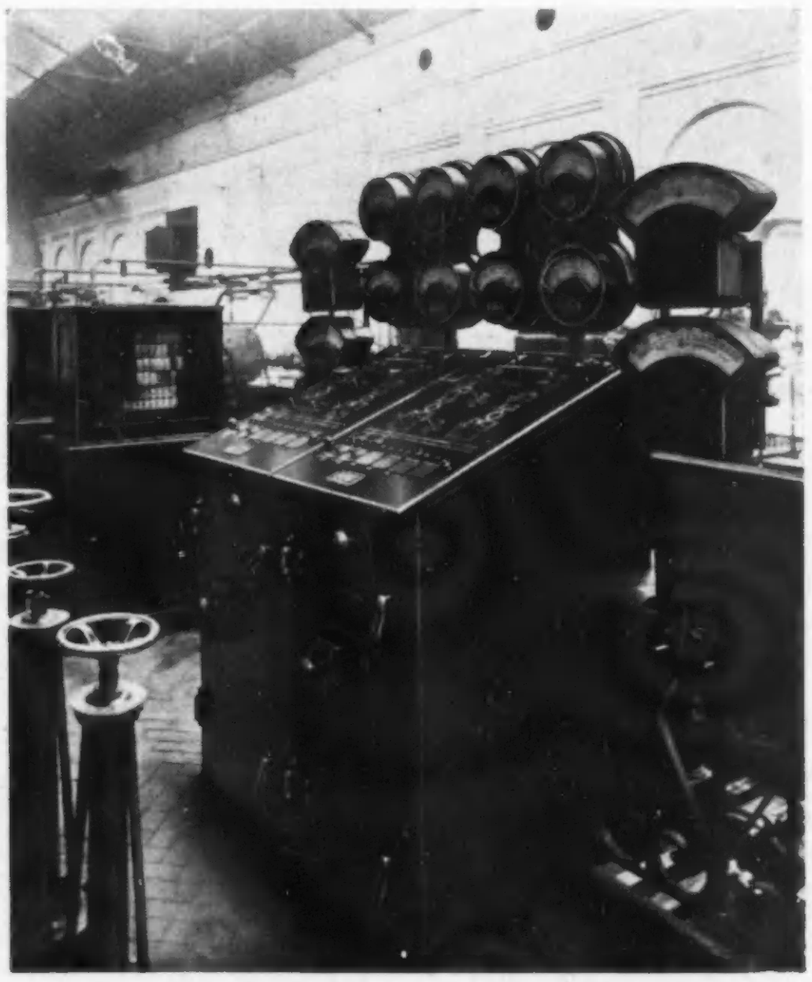


Fig. 3.—Despatcher panels and supervisory cabinets at London Road generating station for control of apparatus at Leigh and Thorpe Bay.

switch at the sub-stations to be controlled and supervised, there is provided on one of the control panels a two-way key, locking in either position. One position is marked "off" and the other "on." Above this key are mounted two lamps, one red and one green.

These lamps and the operating keys are connected together by metal strip forming a single line diagram which is actually a mimic diagram of the circuit arrangement at the controlled sub-station. The attendant is thus able to visualize clearly the actual state of affairs at the sub-station.

APPARATUS CABINETS.

The despatcher and receiving cabinets are very similar, each containing the apparatus necessary to send out and receive signals and perform the necessary selections. The apparatus consists of a number of control relays and rotary selectors of the type used in automatic telephone exchanges where they have proved their reliability during many years.

METHOD OF OPERATION.

To carry out so many operations on only two pilot wires, it is necessary to provide some form of selection before actually sending the impulse which performs the required operation at the sub-station.

The actual operation is very simple; for example, if the switchboard attendant wishes to close an oil circuit breaker at the sub-station, he throws the key on the control panel associated with this breaker from the "off" to the "on" position. This operation sets up circuit conditions, which, by means of a series of electrical impulses transmitted over the pilot wires, first select the corresponding circuit at the sub-station, and then, by means of further impulses transmitted back to the control station, check back to make certain that the correct point has been selected. Finally, an impulse is automatically initiated from the control station which performs the required operation at the sub-station. During these operations the lamp indications change over from green to red. At the moment of the change-over of the indicating lamps correct selection of the point required is indicated, but if this condition lasts for five to eight seconds the indication assures the attendant that the proper operation has been performed.

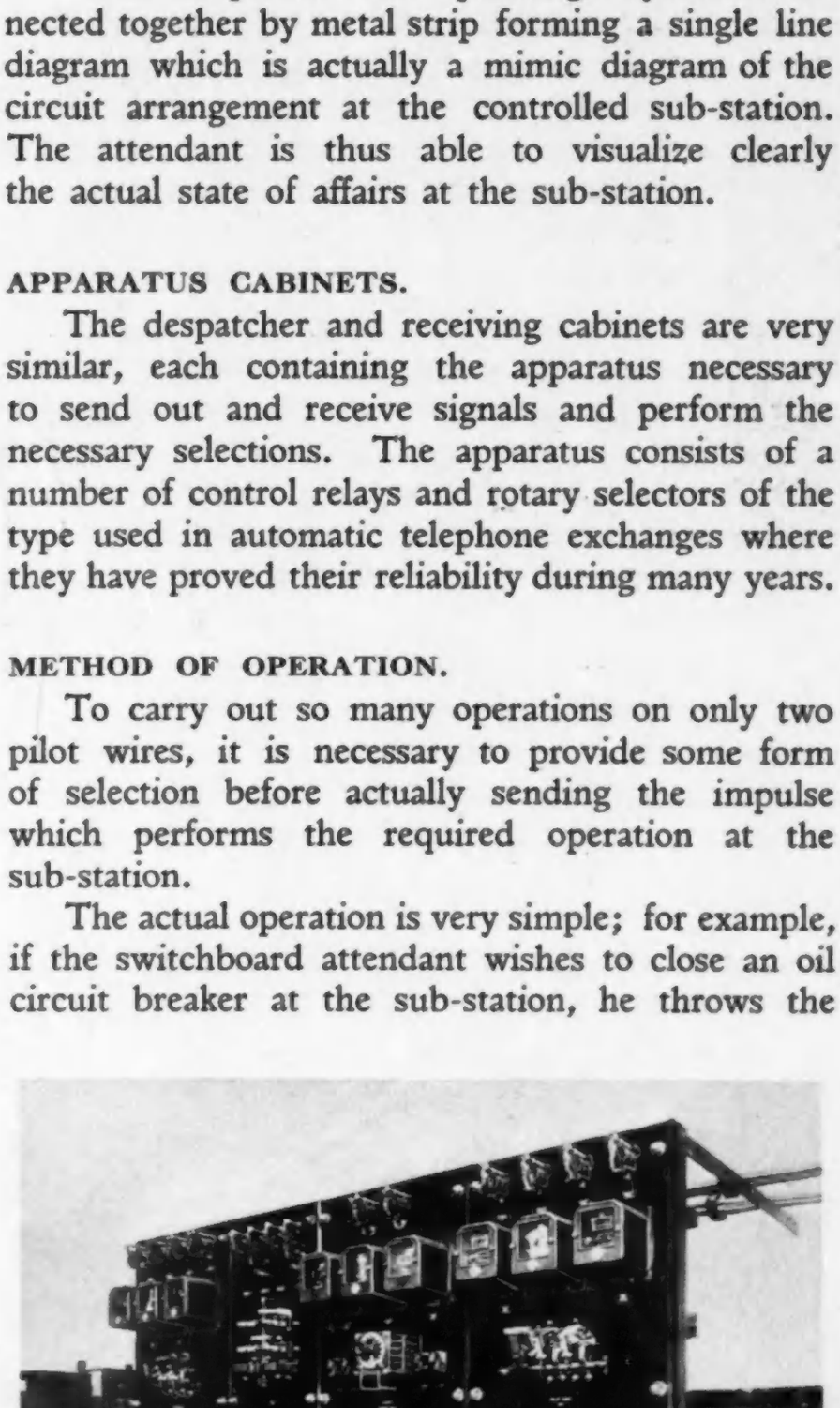


Fig. 4.—Relay panels at Leigh sub-station for automatic control of two 1,000 kW rotary converters.

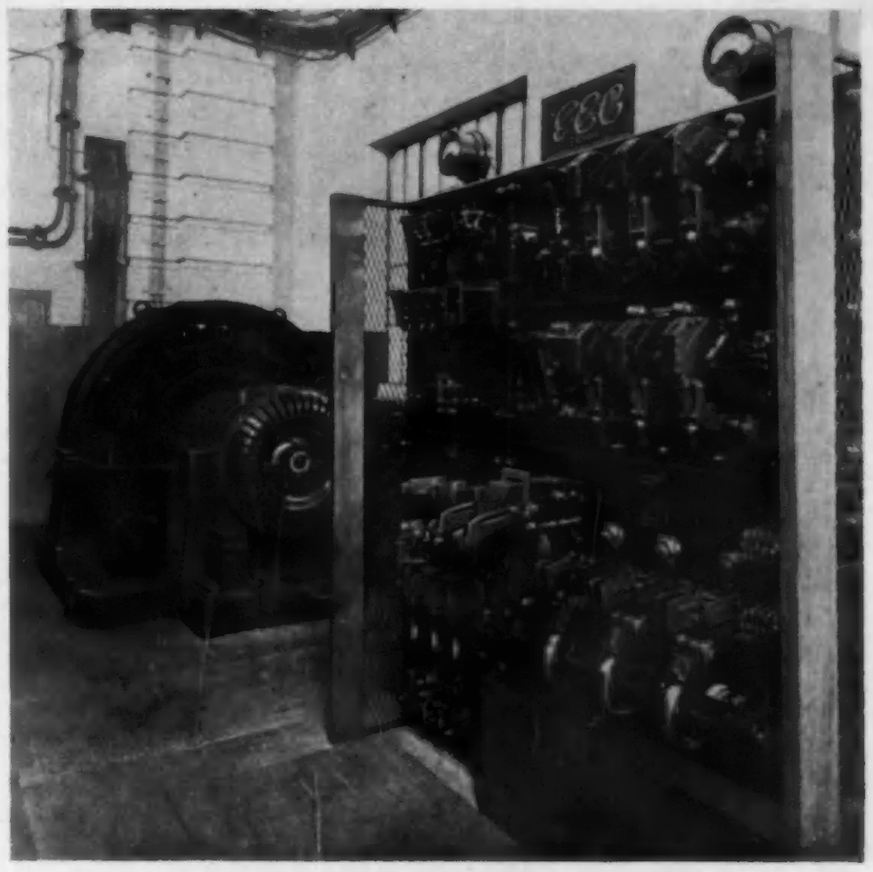


Fig. 5.—A 1,000 kW automatic rotary converter and its starting panel at Leigh sub-station.

Should the oil switch at the sub-station fail to close, or should it trip automatically at any time, signals are sent back to the control station, changing over the indication of the lamps; at the same time a white pilot lamp and bell alarm are operated to draw attention to the change.

The attendant can easily locate the affected switch, as, normally, the key positions agree with the lamp indications and an automatic change would make the lamp indication disagree with the position of the operating key. When the change has been noted, the alarm bell is silenced and the pilot lamp extinguished by resetting the operating key to agree with the lamp indication.

If a number of control operations are made in rapid succession, or if a number of automatic changes occur simultaneously, the signals go through

in a pre-arranged order, the extra signals being stored until the pilot lines are free.

FUNCTIONS OF REMOTE CONTROL EQUIPMENT.

The following operations and back indications are performed by the supervisory gear :—

(*a*) The closing or opening of each machine oil circuit breaker at the sub-station. This operation initiates the starting and stopping sequence for the rotary converters as explained later.

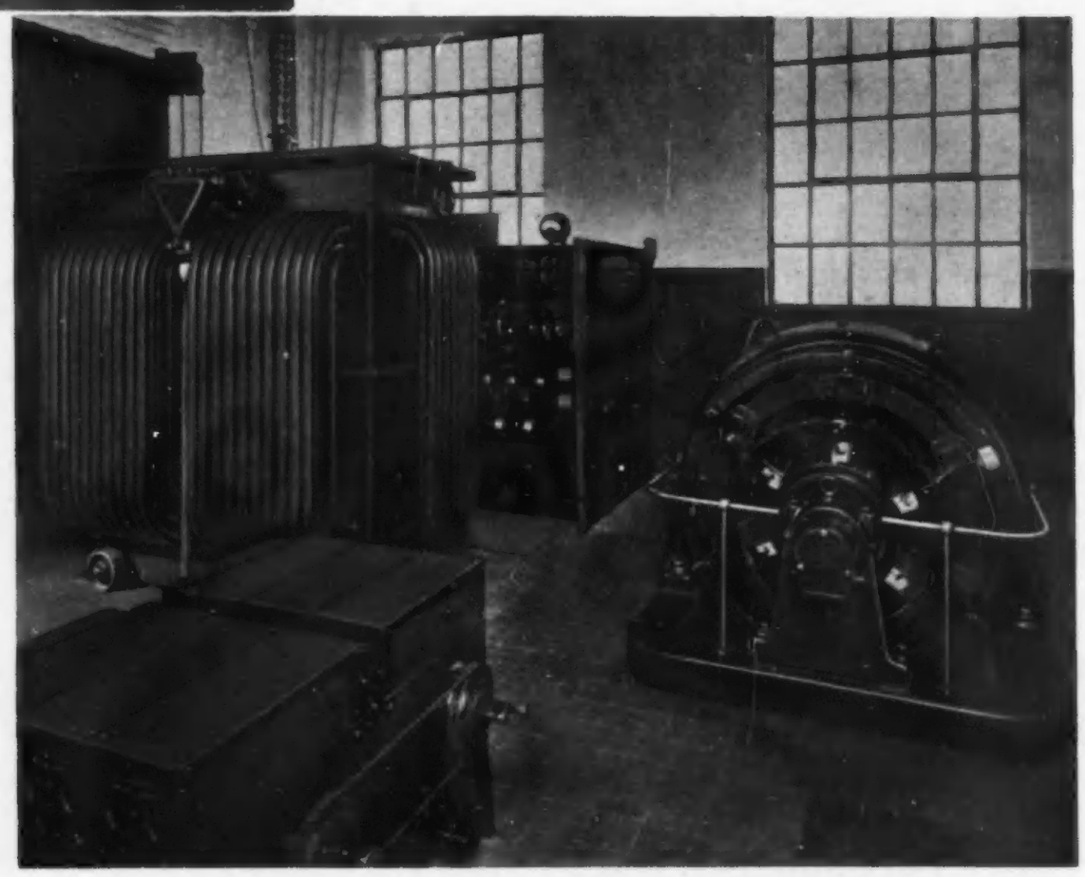


Fig. 6 (*Above*).—**High tension cubicles and relay panels at Thorpe Bay sub-station.**

Fig. 7 (*Right*).—**A 750 kW automatic rotary converter, 825 kVA transformer and starting panels at Thorpe Bay.**

The positions of the oil circuit breakers are indicated at the control point.

(*b*) When the machines have automatically synchronised, an indication to this effect is received at the control station.

(*c*) When the machines are on load an indication is received at the control station.

(*d*) Control and indication of the traction feeders are provided.

(*e*) When the machines are not being controlled by the automatic voltage regulating relay, supervisory control of the field regulators is available.

(*f*) After a general shut down on a large interconnected D.C. system, difficulty is frequently experienced in starting up again, as the first machine to be connected to the bars becomes very much overloaded and is consequently tripped out by the protective relays. To overcome this difficulty, arrangements are made to withhold the closing of the D.C. breaker until all the machines are running ready for load. When remote indications have been received to indicate that this is the case, the switchboard attendant can close all circuit breakers simultaneously by the operation of a single key.

REMOTE METERING.

In order that the switchboard attendant at London Road may fully appreciate the load conditions at the two sub-stations, provision is made for continuous remote readings of the busbar voltage and load on each machine. Three additional pilot wires per sub-station are necessary to operate these meters.

E.H.T. SWITCH GEAR.

The whole of the e.h.t. switchgear consists of interlocked steel cubicles equipped with 11,000-volt, 3-phase, 50-cycle apparatus. At Leigh and London Road stations duplicate busbars are supplied and arrangements are made to allow any machine or any feeder to be connected to either set of bars. To effect a changeover from one set of bars to the other without interruption of the supply, a bus coupler oil circuit breaker is provided at the Leigh sub-station. The bus coupler and all incoming e.h.t. feeders are equipped with hand operated oil circuit breakers, and are normally closed. These oil circuit breakers are all provided with automatic trips to protect the equipment under fault conditions.

The oil circuit breakers for controlling the rotary converters at the Leigh and Thorpe Bay stations are motor operated and controlled either by the automatic starting and stopping relays in the sub-stations, or by the supervisory control gear

from the main station. The machine oil circuit breaker for the non-automatic set at London Road is hand operated and automatically protected in the usual way.

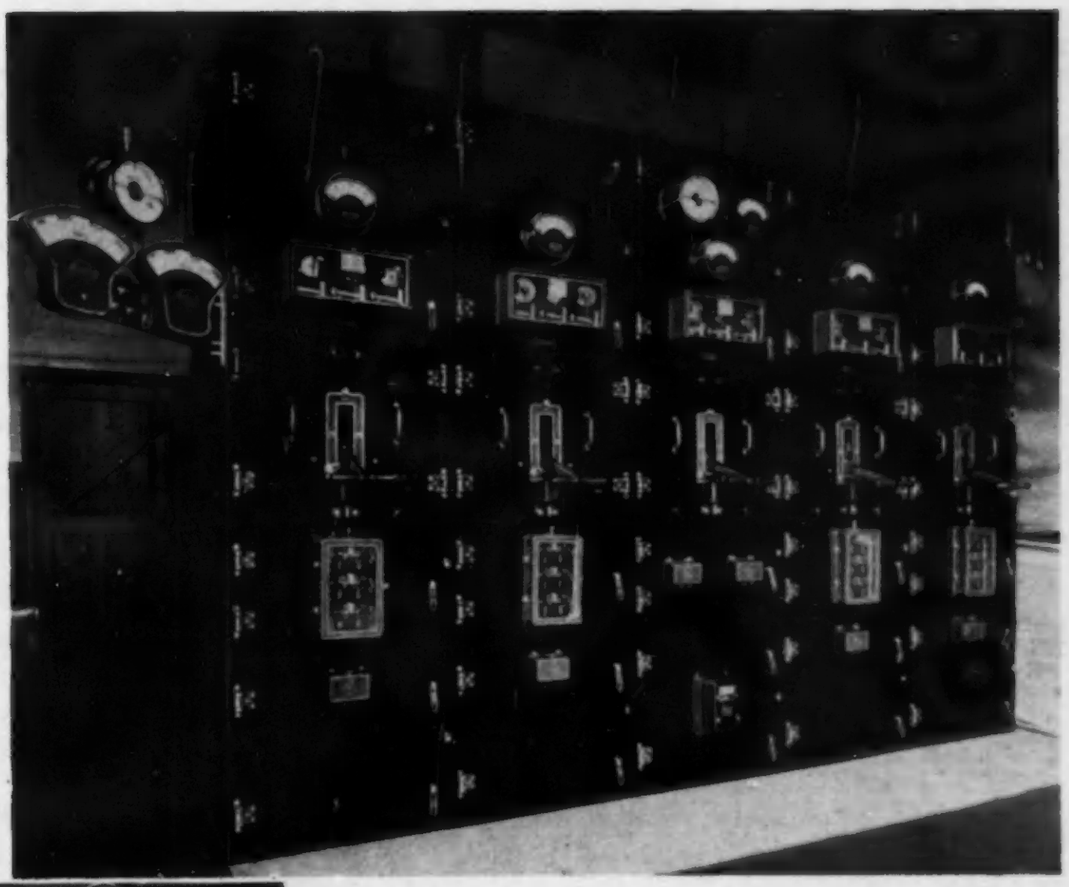
SEQUENCE OF OPERATIONS AT THE SUB-STATIONS.

As the non-automatic rotary converter at London Road is a standard equipment, the method of operation is well known and no further reference to this equipment is necessary. It will be of interest, however, to describe briefly the method of automatic operation adopted by the G.E.C. as applied to motor-started rotary converters.

The main power connections are similar to those required for a non-automatic rotary converter, although the field connections are slightly more elaborate in order to give the correct starting resistance during synchronising. Special conditions exist at Leigh, as a high voltage lighting network has also to be supplied with current; further reference to this is omitted from this description, but its operation is generally similar to that of the traction network.

STARTING UP (TRACTION).

By operating the supervisory control gear at London Road a power relay is energised, closing an auxiliary contactor which starts up the motor for operating the machine oil circuit breaker, *i.e.*, provided conditions are ready for a start. When this motor attains a certain speed, a centrifugal switch operates and causes the motor mechanism to engage with the oil circuit breaker mechanism, and the energy stored in the motor flywheel closes the oil circuit breaker. The motor is then stopped automatically.



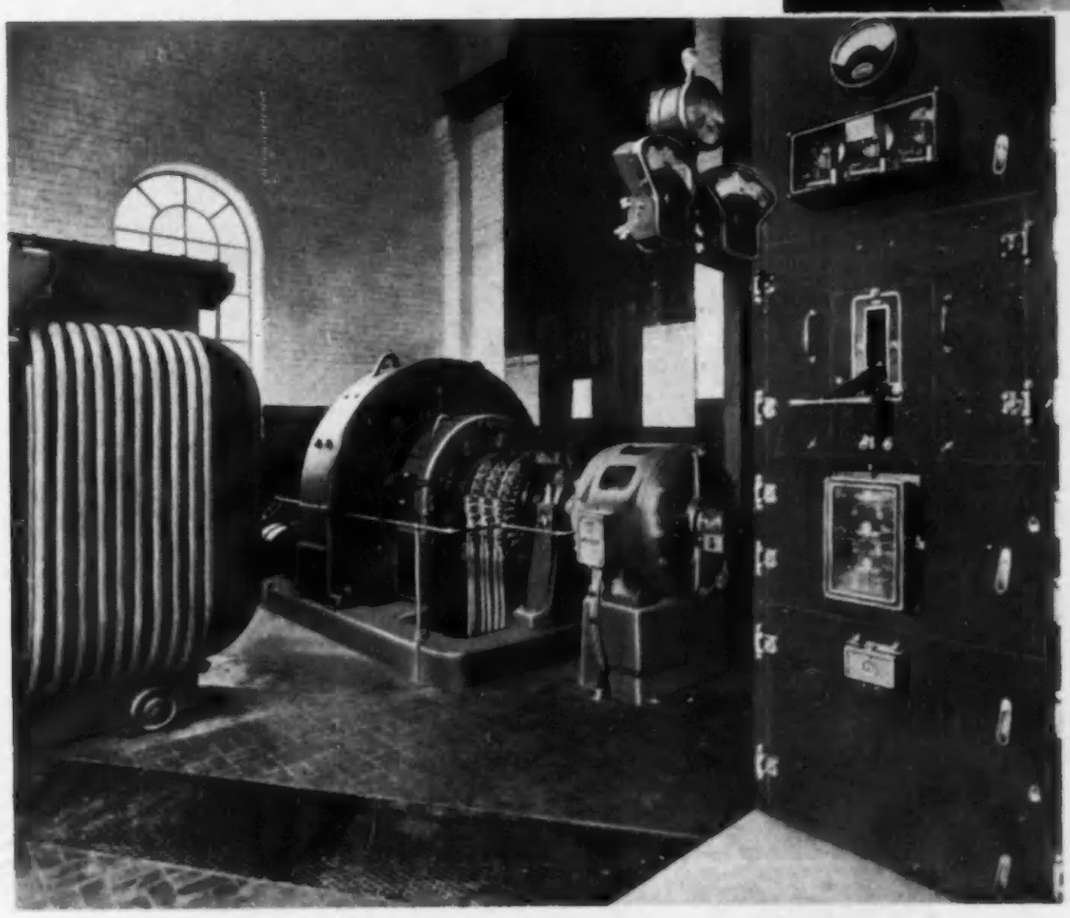


Fig. 9 (*Above*).—**High tension cubicle switchboard at London Road.**

Fig. 8 (*Left*).—**1,150 kW hand operated rotary converter at London Road.**

The closing of the breaker energises the main transformer and closes the starting contactor, thus energising the pony motor. The rotary converter runs up to speed, and when the field has grown to a predetermined value, the synchronising contactor closes, applying the main transformer voltage to the slip rings and to the synchronising choke coils in series. The machine pulls into step and is held there by the current passing through the choke coils. A few seconds after the machine is held in step, the running contactor is closed by means of the synchronising relay. At the same time the starting and synchronising contactors are opened by means of interlocks.

Before starting, a definite resistance is inserted in the field by means of a two-way field contactor; when the running contactor closes, the field circuit is restored to normal. To ensure that the machine builds up with the correct polarity, a polarising motor-generator is connected during the starting period to a special polarising field system on the machine. Various contacts prevent incorrect operation of the running contactor if any fault exists.

When the running contactor closes, the machine is synchronised on the A.C. side. If the D.C. voltage has built up to normal value, the voltage relay begins to operate and (after a few seconds to allow the machine to settle down into synchronism)

the D.C. circuit breaker closes. The machine is now connected through the load limiting resistances to the traction busbars, and, after a time delay, the main D.C. contactors are closed, cutting out the load limiting resistances. The busbar voltage will remain constant for a particular load, but it can be adjusted from London Road by means of the motor-operated field regulators.

STARTING UP (LIGHTING).

With supervisory control the operations are similar to those described for traction, but if a machine is started up when no load is available, it is automatically shut down again after a time lag.

With automatic operation, when the busbar voltage falls below an adjustable predetermined value, the low voltage relay makes contact and energises the sequence relay. After a time interval this relay makes contact and, provided that all is in order for starting, causes the oil circuit breaker of the next machine in the sequence to close. The machine then runs up and synchronises automatically with the A.C. supply. The D.C. circuit breakers then close, switching the machine on the D.C. network through load-limiting resistances.

At this point a paralleling relay comes into operation and adjusts the machine voltage to the correct value for paralleling. Finally, this relay allows the contactors for short circuiting the load limiting resistances to close. At the same time the voltage regulating gear comes into operation and maintains a constant busbar voltage. The setting of this relay may be varied from London Road.

When the first machine has been fully loaded for a specified time (or if it should fail to complete the normal starting sequence), the second machine automatically starts up and parallels with the first machine, its field being adjusted to take its proper share of the load.

SHUTTING DOWN.

The machine oil circuit breaker may be opened either automatically or by supervisory control from London Road. With automatic operation, when two machines are running in parallel, the machine which has been running longer is automatically shut down when the load falls to a predetermined value ; if the load still falls to a lower predetermined value the second machine is automatically shut down. When the oil circuit breaker is opened, the D.C. circuit breaker is also tripped, and all the gear is reset for the next start. As each machine is shut down, the fact is signalled back to London Road.

TRACTION FEEDERS.

The feeder circuit breakers are closed by supervisory control, the closing being signalled back to London Road. If a breaker trips on overload, it is automatically reclosed after 15 seconds ; should the overload persist, further reclosing is prevented after the circuit breaker has been opened and automatically reclosed a specified number of times.

PROTECTION.

By means of various relays the protective system minimises the dangers and inconvenience of faults in the apparatus or line. Faults may be classified as (1) A.C. faults external to the station, in which the plant is prevented from running until the faults are rectified ; (2) Serious faults in the plant itself, which operate the lock-out relay, preventing re-starting until the relay is re-set by hand ; (3) Faults in the D.C. system, which lock-out the machines only after the D.C. circuit breaker has reclosed several times.

The protective apparatus operates in the following circumstances :

(*a*) Low A.C. voltage, reversed or broken phase.
(*b*) Excessive A.C. overload.
(*c*) Earth leakage (on transformer or machine).
(*d*) Unbalanced phase current.
(*e*) Reversed polarity.
(*f*) Overspeed.
(*g*) Unduly long synchronising or paralleling periods.
(*h*) D.C. reverse current.
(*i*) Excessive D.C. overload.
(*j*) Overheating of windings.
(*k*) Over voltage (on D.C. lighting network).

LOCAL CONTROL.

Finally, it should be mentioned that a control panel is installed in each sub-station to give local control from push buttons ; on local control the machines still synchronise and parallel automatically and all the protective features are operative. The voltage regulation may remain automatic or may be controlled by push buttons as desired. Emergency hand control is also available if for any reason the automatic gear should be out of commission.

Twenty-five Years of Steam Turbine Development.

By B. Pochobradsky, M.I.Mech.E.

Chief Engineer, Fraser and Chalmers Engineering Works of The General Electric Co., Ltd.

As Fraser & Chambers have just completed their 25th year of turbine manufacture, this article is in the form of an historical sketch. While there have been inevitable modifications in the design and manufacture of their turbines, chiefly due to increase in sizes of units and higher steam pressures and temperatures, it is shown that a consistent policy has been followed throughout, having as its main objects high thermal efficiency, reliability, and ease of maintenance.

FRASER & CHALMERS started to manufacture steam turbines twenty-five years ago. The first turbines were built to the designs of the late Professor Rateau, the great inventor and designer, who must be regarded as the originator of the commercial multi-stage impulse turbine which gave new direction to the turbine industry.

In the original Rateau turbines the wheels consisted of two discs riveted to a hub keyed on the shaft. The blades were stamped out of mild steel strip and were provided with forked ends which straddled and were riveted to the discs. The stationary blades were pressed out of sheet brass, riveted at the top and bottom to ring segments and inserted in suitable openings of the diaphragms.

The peripheral and steam velocities were moderate and, in many instances, turbines with two casings were built with a considerable number of stages. Ample clearances between rotating and stationary parts were particularly responsible for the popularity of the Rateau machine.

In the course of a few years very substantial changes took place in constructional details; solid discs were adopted for wheels. The moving blades were milled out of rectangular bars and the stationary blades, made of steel, were cast in the diaphragms.

In 1911, while adhering to the principles of the multi-stage impulse turbine, new designs were developed, of which the main features include a Curtis wheel as the 1st stage, followed by Rateau stages, automatic nozzle cut-out governing, higher peripheral speed, fewer stages, shorter and simpler machines, labyrinth packings with stationary brass rings and rotating steel sleeves protecting the shaft from accidental contact.

A 3,000 r.p.m. turbine design as developed in 1911 is shown in fig. 1.

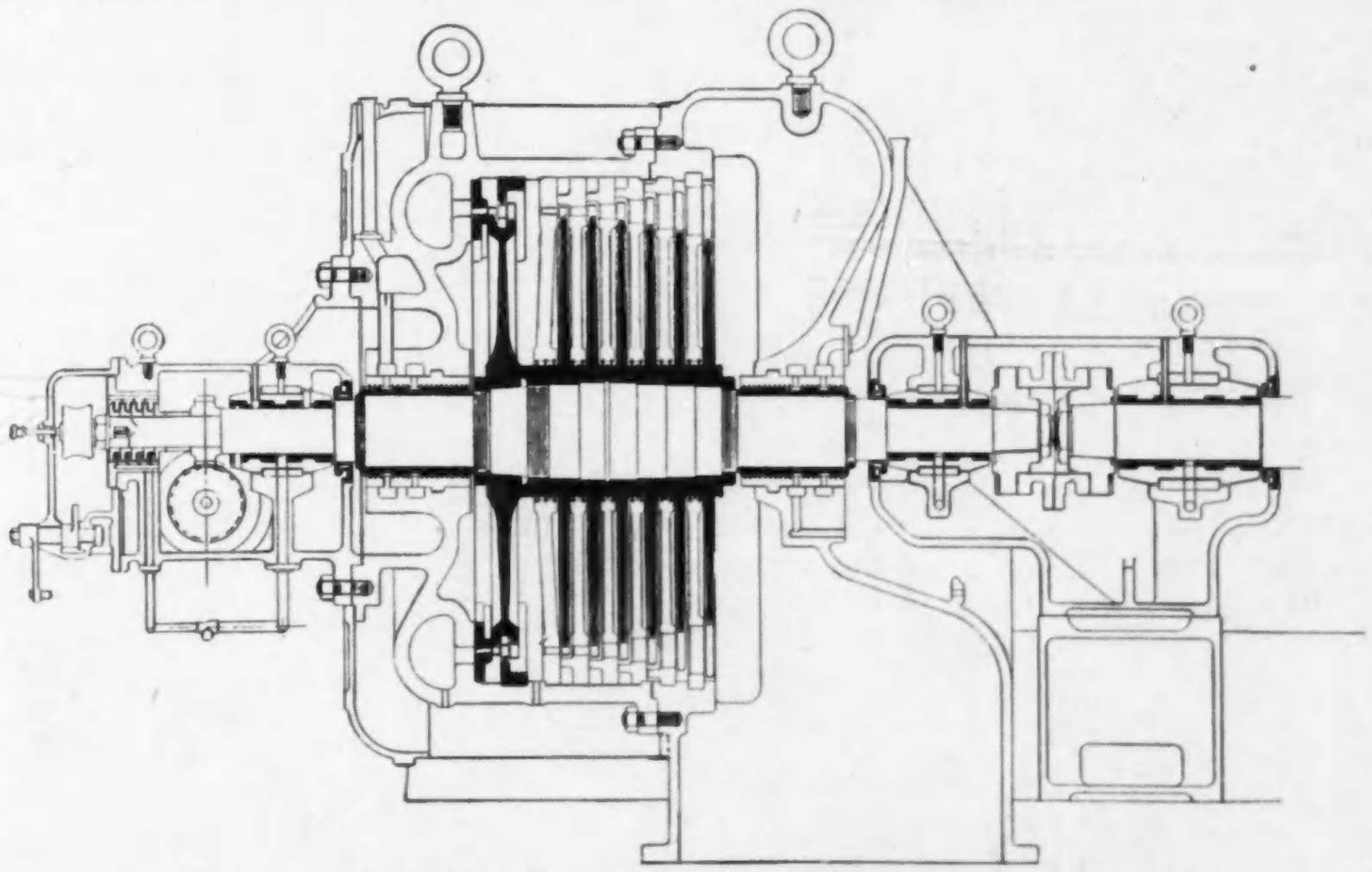


Fig. 1.—Section of high pressure, 3,000 r.p.m. turbine as developed in 1911.

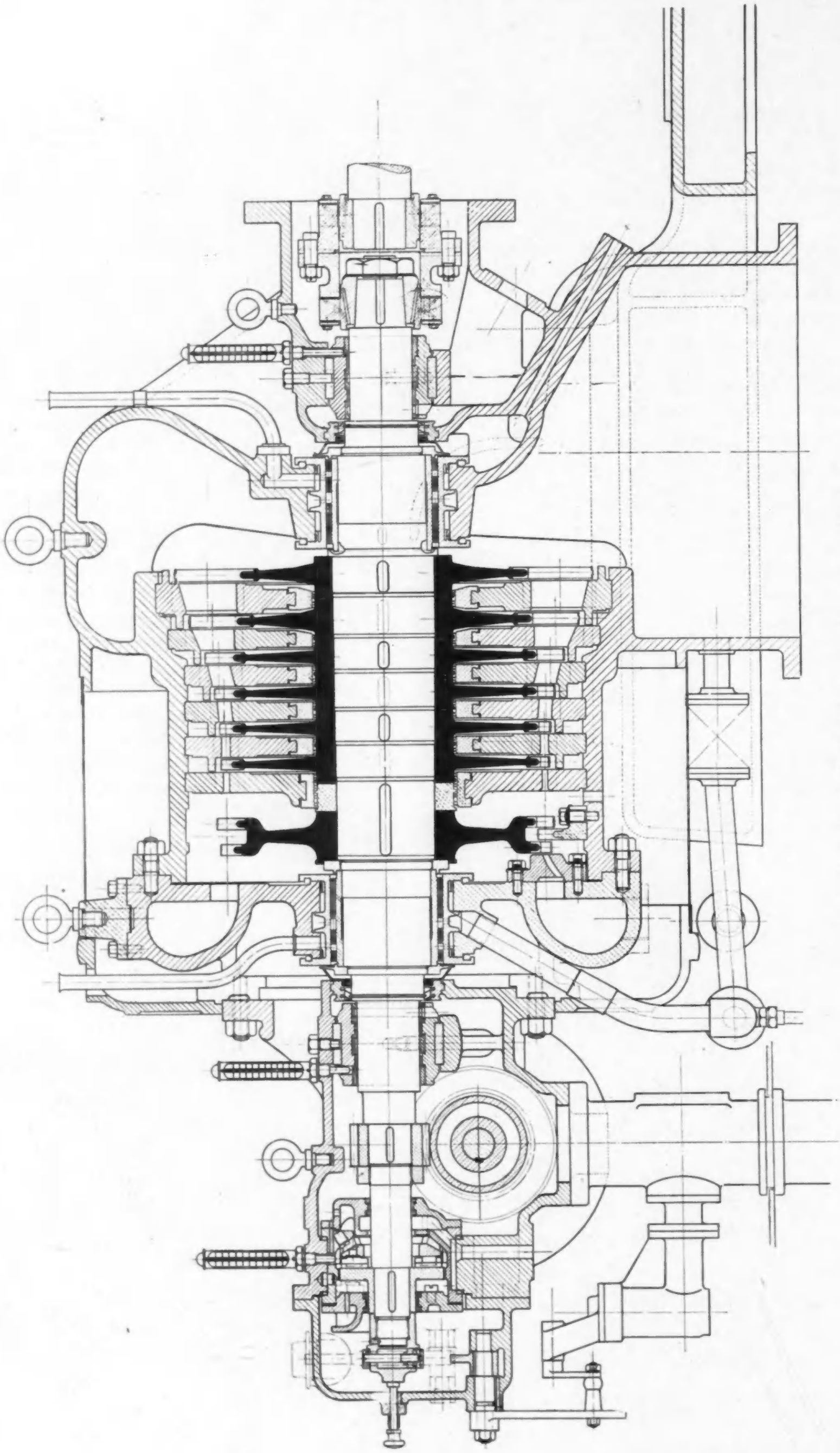


Fig. 2.—Section of a 6,000/7,500 r.p.m. disc type turbine.

With the new design was coupled a reorganisation of manufacture. For this purpose the turbines were divided into three main speed groups—4,500 r.p.m., 3,000 r.p.m., 1,500 r.p.m.—and while other speeds have been applied, as a rule such machines were based on one of these speed types.

All three speed types had a number of common parts, such as governor, stop valve, control valves, oil cooler, oil pump, blade sections and oil relays. These parts were stock manufactured, thus reducing the cost of production, shortening the delivery and levelling out the inevitable fluctuation of work to orders. Further, each of the three speed types had parts common to a large number of machines of that type, including bearing pedestals, bearing shells, worm drive, oil pump drive, exhausts and packings, and these parts were again stock manufactured. In fact, in most cases a large number of parts of the turbine were simply drawn out of stock, while the blades, discs, diaphragms, and the high pressure end of the casing were the only parts which normally were manufactured for a given order.

This organization of manufacture is maintained to-day, but naturally it is adjusted to suit more modern conditions arising out of a greater variety of speeds, outputs, drives, steam conditions and heat economy.

OUTPUT.

The development of the turbine from the point of view of output per set may be exemplified by the 3,000 r.p.m. type. In 1912 the largest machine at that speed had a normal output of 1,500 kW while in 1913 and 1915 respectively the first 3,000 kW and 5,000 kW turbines were produced.

For some time progress was held up on account of unsettled general conditions, but in 1920 the first 10,000 kW 3,000 r.p.m., and in 1923 the first 15,000 kW 3,000 r.p.m. machines were manufactured, and in 1929 the first 30,000 kW 3,000 r.p.m. machine was built. Thus, within seventeen years the output per turbine has increased twenty times.

In this increase of output the last stage played an important part. This stage was to some extent a limit to the size of turbine.

It may be of interest that the output of the last wheel in the above mentioned 1,500 kW turbine was 190 kW with a vacuum of 28½ins., while in the 30,000 kW turbine one single wheel in the last stage produces 2,000 kW with a vacuum of 29ins. With unaltered dimension of this last wheel, but with a vacuum of 28ins., the output of that wheel would be 3,800 kW. The larger output of the last wheel has been obtained by increasing the diameter of the wheel and the length of blade; in other words, by a higher peripheral velocity and an increased leaving area. In 1912, the peripheral velocity, measured at the tip of blades in the last stage, reached 655ft. per sec.; in 1915 780ft. per sec.; in 1921 950ft. per sec.; in 1925 1,000ft. per sec., while the leaving area of the last stage grew from 6.5 sq. ft. in 1912 to 21.5 sq. ft. in 1925. All these figures refer to 3,000 r.p.m. turbines.

EFFICIENCY.

Parallel with the increase of output per set is the improvement in efficiency. While the 1,500 kW turbine built in 1912 had an efficiency of 70 per cent. (referred to adiabatic heat drop from stop valve steam conditions to vacuum in exhaust), the 30,000 kW of 1929 reaches the figure of 85 per cent. The improvement is better appreciated when the losses are compared. While the losses in the 1912 turbine amounted to 30 per cent. of the available adiabatic heat drop, they are only 15 per cent. in the 1929 turbine. This increase in efficiency is partly due to increased size, leakage losses, friction and ventilation losses, bearing and other mechanical losses representing a smaller percentage of the total output in the larger machine. On the other hand, there are other factors tending to improve the turbine efficiency and not directly attributable to increased size. In this connection should be mentioned the reduced diameter in the high pressure part of the turbine, which means increased height of blades or increased width of the belt of the steam flow. Further, the increase of the ratio of peripheral velocity to the steam velocity in a stage has the result of "flattening" the absolute path of steam through a stage. The improvement of the blade profiles gives smooth flow with gradual changes. The angles of the stationary blades are made so that they vary along the inlet and outlet edges to suit the varying peripheral speed at different points of the blade height. This construction eliminates the shock losses due to unsuitable angles and, at the same time, ensures that the areas through the blades suit the different steam velocities so that the expansion of steam in the blades is uniform right throughout the height of the blades.

Finally, the introduction of a new labyrinth packing, having a much larger number of labyrinths in the same length than the older packing, has substantially reduced leakage losses.

STEAM AND HEAT CONSUMPTION.

Apart from the improvement in efficiency there have been other factors in the evolution of the turbine which have caused a reduction in steam consumption or heat consumption. While the steam pressure of 200 lbs. per sq. in. in 1912 was considered satisfactory, to-day 350 lbs. per sq. in. is very usual and still higher pressures are being adopted. For large stations with a good load factor, a pressure of 600 lbs. per sq. in. is considered as economically justified. For base load plant, a

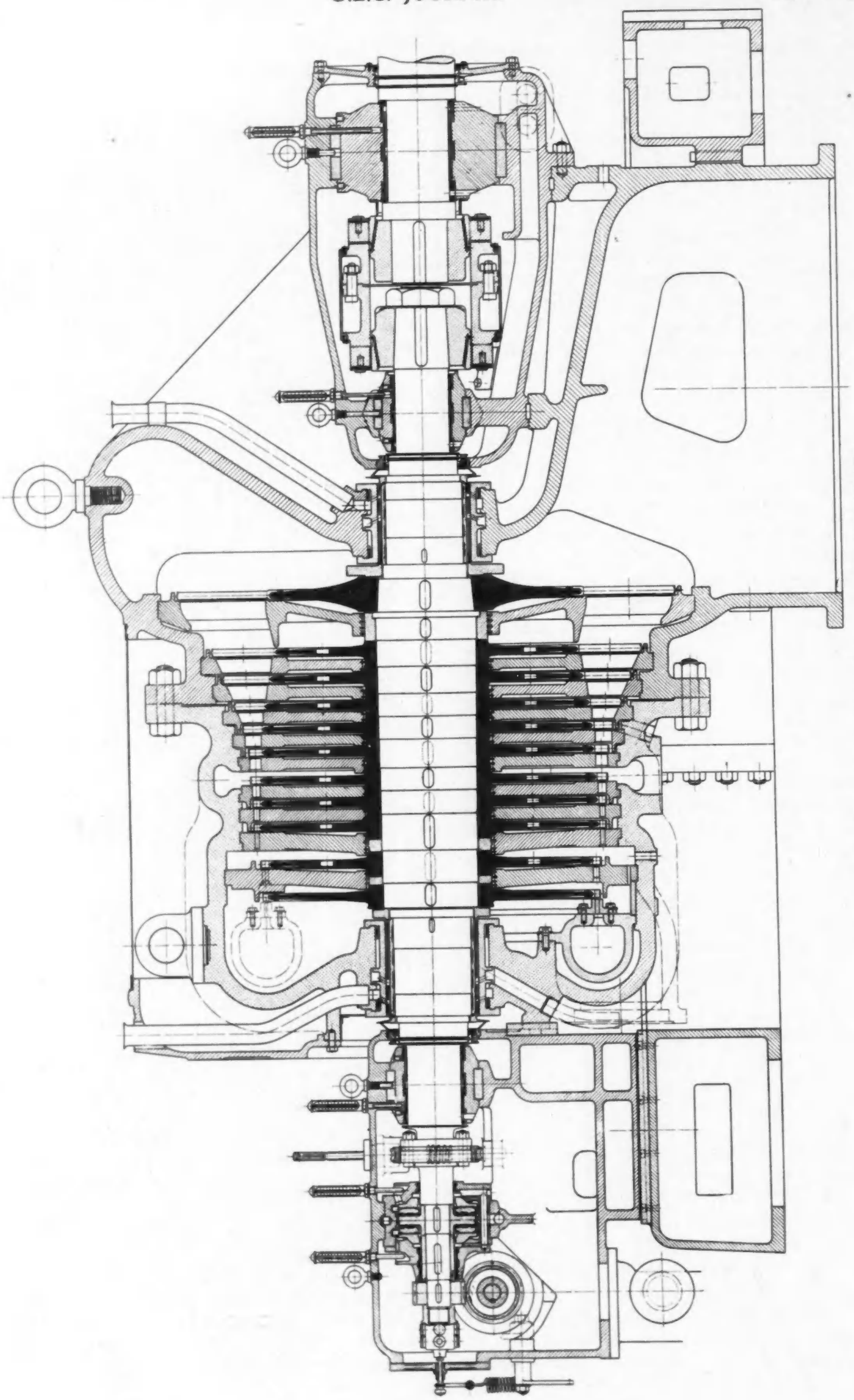


Fig. 3.—Section of a 5,000 kW, 3,000 r.p.m. disc type turbine.

pressure of 1,200 lbs. per sq. in. is likely to show a commercial advantage.

The effects of the increased steam pressure are two-fold—first in regard to steam or heat consumption, and second in regard to the mechanical design of the turbine. Assuming a vacuum of 29ins. and an initial steam temperature of 700° F., it will be found from a steam diagram that the available adiabatic heat drop increases with increasing pressure, the increase being, however, a gradually diminishing one until, at a pressure of about 1,400 lbs. per sq. in. the adiabatic heat drop reaches its maximum. Increased pressure beyond that figure would mean a gradual decrease in the adiabatic heat drop. With the same vacuum but with an initial temperature of 900° F. the adiabatic heat drop reaches its maximum at a pressure of about 2,200 lbs. per sq. in., while it is smaller for lower or higher pressures than this. It will be clear that, with an initial temperature of 700° F., an increase of pressure beyond 1,400 lbs. and with an initial temperature of 900° F., an increase of pressure beyond 2,200 lbs. per sq. in. would mean a turbine with increased steam consumption. On the other hand, the heat content at the higher pressures decreases, with the result that the heat consumption, which after all is the main criterion, diminishes with pressures higher than the above figures, this decrease being more pronounced with higher initial temperature.

With increased pressure higher forces have to be dealt with and the design must therefore be considered specially from this point of view. In addition there has to be taken into account the increased cost of plant, which is particularly perceptible on small plant. The percentage increase of cost due to increased pressure diminishes with increasing size of plant—hence the general tendency for the adoption of moderate steam pressures for smaller plant and higher steam pressure for large plant. It is not possible, however, to make any definite statement as to the best steam pressure to be applied.

While general principles are a guide, a large number of cases must be considered on their particular merits. Apart from the first cost of the plant, the load factor and the fuel cost are the most important factors to be considered when determining the most economical steam pressure.

MOISTURE CONTENT.

For a given steam temperature at the inlet and vacuum at the exhaust and for a given turbine efficiency, the moisture content in the low pressure part of the turbine increases with increased initial pressure. The effects of increasing the moisture content are reduced turbine efficiency and reduced life of blades due to operating in wet steam. Various methods are being applied to reduce the detrimental effect of increased moisture content. These include increasing the initial temperature of steam, re-superheating steam after partial expansion, and eliminating some of the moisture out of the blading. The re-superheating shows only a small thermal gain as against considerable complication and extra initial costs. This complication is particularly serious when re-superheating is done by means of boiler flue gases. Re-superheating by means of live steam is simpler and has better chances. On the whole, however, re-superheating is not likely to establish itself firmly for pressures below 800 lbs. per sq. in.

Experience shows that stainless steel (13 per cent. Chromium) blading has longer life than 5 per cent. Nickel steel blading under the same conditions of wetness and velocities of steam. So far as can be seen with steam pressures up to 400 lbs. per sq. in. and 800° F. steam temperature, stainless steel blades have a very reasonable life, but for higher steam pressure with increasing moisture content in the L.P. part of the turbine, especially in the last stage, better materials are being evolved.

The method in which partial elimination of moisture is obtained is based on the fact that, owing to centrifugal action, the moisture tends to concentrate near the blade tips and some of it is thrown out in the clearances between the stationary and moving blades. A ring channel is provided around the L.P. wheels, these channels being fitted with deflectors for the separated water and with catchers to prevent the separated water returning to the turbine blades. The water so separated is drained at the bottom of the casing from stage to stage into the condenser.

In connection with steam pressure, mention must be made of combined power and heat plants where steam produces power in steam turbines and is subsequently used for heating purposes as is the case in paper factories, chemical factories, textile factories and the like. In such instances the steam used for heating expands in the turbine to a pressure of 10 to 100 lbs. per sq. in., or even more. With such back pressures the available adiabatic heat drop increases much more with increasing steam pressure. Increased steam pressure may therefore have a greater commercial advantage than in ordinary condensing steam turbine plant. Apart from this, the moisture difficulty in the L.P. end does not exist at all when back pressure turbines are used, or exists only to a very much smaller extent when passout machines are used.

The increase of the initial steam temperature reduces the moisture content in the L.P. part of the turbine and so improves its efficiency, but at the same time the increased steam temperature causes an important increase of the available adiabatic heat

drop. Hence the increase of initial steam temperature is, from the point of view of thermal efficiency, very desirable. On the other hand it is limited by the materials used for superheaters, piping, steam chests, valves and high pressure parts of the turbine. The principal factors involved are temperature expansion, heat stresses, scaling properties of metals, resistance of metals to deformation and fracture, and critical vibration of shaft and other parts.

DESIGN FOR HIGH TEMPERATURES.

With increasing temperature the expansion of metals increases for a given dimension. Longitudinal clearances in the high temperature part are made sufficient to take up the greater part of the expansion. In a radial direction the turbine is made in small dimensions so that the total expansion in a radial direction is also kept within reasonable limits, and finally those parts of the turbine which co-operate and which are subjected to high temperature, are made of either the same metals or metals having practically the same co-efficient of heat expansion. The support of the high pressure casing of the turbine is arranged in close proximity to the horizontal centre plane so that the total temperature expansion in a vertical direction is also within reliable limits. Finally, the expansion of the whole turbine as a unit being greater on account of the higher steam temperatures adopted and by reason of the increased length of the turbine, a special arrangement is employed in two cylinder machines by means of which the whole stationary part expands as a unit from a fixed point, while the relative expansion of the rotors is sub-divided in two parts—high pressure and low pressure—a thrust bearing being arranged between the two parts.

Heat stresses arise as a result of temperature differences. While such temperature differences exist both in the stator and the rotor even in continuous operation, they reach very high figures during starting. The temperature differences, and consequently the heat stresses can be reduced if the thickness of the various parts is reduced. This is achieved by making those parts subjected to high temperature steam of small dimensions. The casing is made of small diameter and consequently the thickness of the walls can be kept within moderate dimensions ; the rotor is made as a simple sleeve of moderate thickness and uniform dimensions ; the stationary blades are fixed on small rings and the diameter of pipes and steam chest is reduced by duplication.

It is well known that physical properties of metals are seriously affected by higher temperatures. Generally, it must be realised that the metals in a steam turbine are stressed continuously. At higher temperatures the metals, when stressed above a certain limit, would "creep." For this reason the stresses must be kept well below the limiting creep stress, which is naturally well below the ultimate tensile strength belonging to the temperature in question. At high temperatures the limit of proportionality is also substantially reduced.

There are two factors in high temperature steam turbines which provide for safety from this point of view. The first is generally reduced dimensions and, as a consequence, generally reduced forces producing the stresses. The second is the use of special alloy steels containing Molybdenum, Tungsten, Chromium, Nickel and other ingredients. These steels have considerably higher limits of proportionality and higher limiting creep stress, and their use makes it possible to make the various parts of the turbine of comparatively small thickness which, as previously indicated, is so highly desirable from the point of view of heat stresses.

All critical vibrations depend on the modulus of elasticity of the materials used. The modulus of elasticity of steel decreases with increasing temperature. Thus, at 800° F. a given shaft would have an appreciably lower critical speed than at 600° F. Similar conditions obviously exist for other critical vibrations, such as the vibration of discs or blades. Turbines for extra high temperatures have no discs in the high temperature zone, and the difficulty of disc vibration is thereby entirely eliminated. The blades are so designed that resonance is avoided within a large temperature range, particularly at the normal temperature.

FEED HEATING.

For some years past, regenerative feed heating has been applied. This consists in tapping steam from one or more stages of the turbine and using it for heating up the condensate in one or more successive heaters. The thermal gain depends on the number of feed heaters and on the temperature to which the feed water is raised. A greater number of feed heaters gives greater thermal gain, but the increase in the gain gradually diminishes. In actual practice more than four feed heaters are seldom used. For smaller plants one feed heater is usually applied. The thermal gain increases with the feed temperature, this increase being a gradually diminishing one until a temperature is reached at which the thermal gain represents a maximum, after which the thermal gain begins to decrease.

As the heating steam is tapped from the turbine at some stage before the exhaust end, it follows that this steam works in the turbine with a reduced heat drop and therefore the steam consumption of the turbine will increase. On the other hand, this steam being partly expanded in the turbine and condensed in the feed water heater, practically the total heat contained in the tapped steam is utilized, thus giving a thermal gain.

In order to obtain the best results, it is necessary to design the turbine for the steam quantities actually working in the different parts of the turbine. It will be obvious that the performance of steam turbines working with feed heating cannot be judged by the steam consumption, the proper criterion for such turbines is heat consumption, a figure arrived at by crediting the turbine plant with the heat which it supplies to the boiler plant.

TYPES OF CONDENSING STEAM TURBINES.

For smaller outputs, say between 300 kW and 2,000 kW, turbines are of the multi stage type, running at speeds of ~~7,500~~ 1500 to 6,000 r.p.m. Should the driven machine be unsuitable for developing such speed, it is connected to the turbine by means of a speed reduction gear. High turbine speed allows of small diameter, and results in reduced friction, ventilation and leakage losses and in increased blade height which, especially in the high pressure part, produces a substantial improvement in efficiency. Such a turbine is illustrated in fig. 2. It will be seen that it is the well known disc type.

For medium outputs a similar disc type of machine is used. A 3,000 r.p.m. machine of 5,000 kW is illustrated in fig. 3.

For larger outputs the efficiency becomes of greater importance relatively to the cost of the machine. The method of obtaining this increased efficiency is to increase the ratio of peripheral velocity to the steam velocity per stage and, at the same time, to reduce the diameters in the high pressure part to such a degree that blades of substantial lengths can be applied. This principle is incorporated in the turbine shown in fig. 4. It will be seen that the first stage is of the disc type having a moderate diameter. The heat drop utilised by this stage is sufficiently large to permit the use of nozzle cutout governing. Usually four throttle valves are supplied, each valve controlling a separate nozzle block. The following stages are of smaller diameter and have full steam admission. The diameter is so small that the moving blades are mounted on a drum carried by the shaft. The stationary blades are machined in a similar way to the moving blades and are attached to the casing by means of rings to which the blades are fixed. The leakage is reduced to a minimum by means of labyrinth glands fitted on the inner end of the stationary blade. The drum is followed by a number of disc stages.

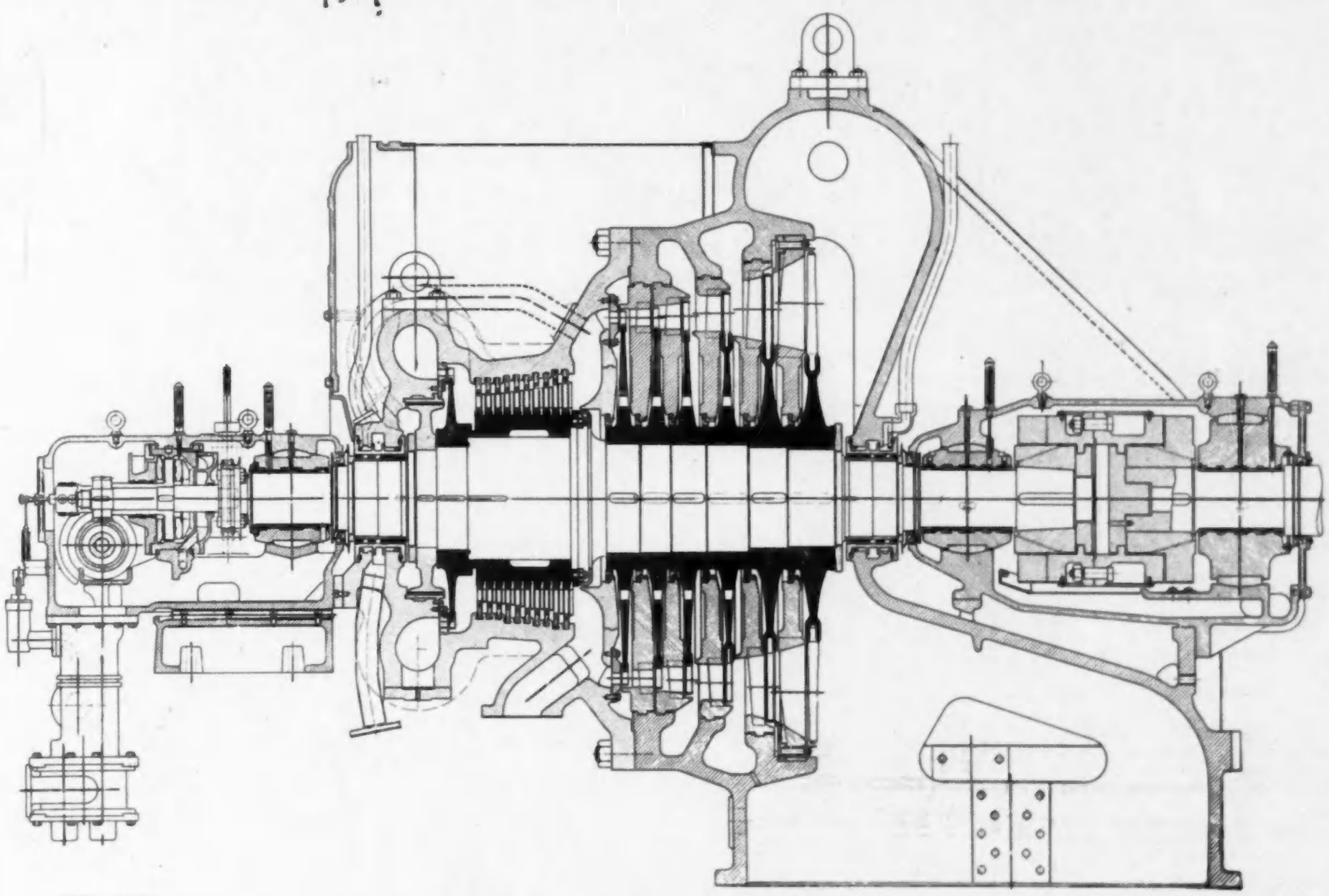


Fig. 4.—Section of high efficiency turbine of large output.

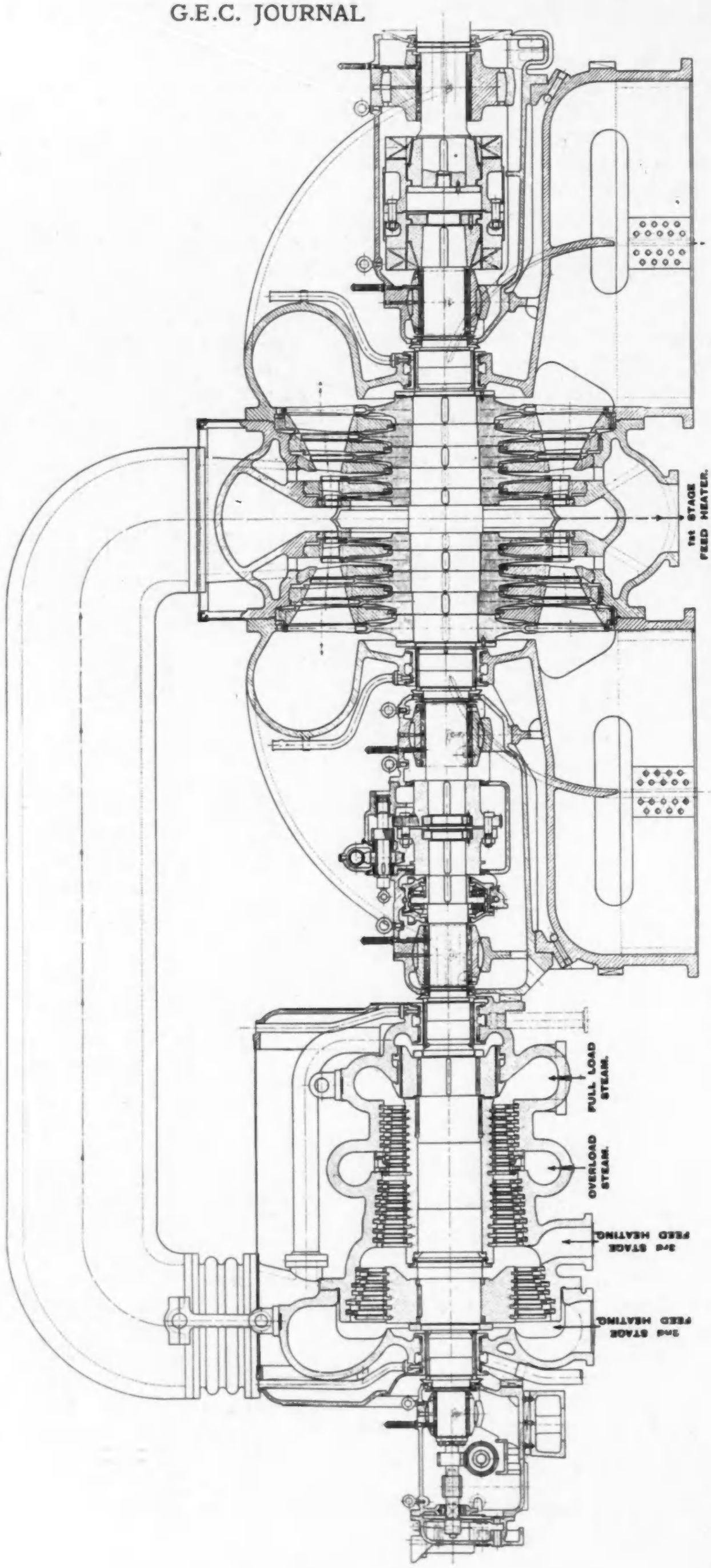


Fig. 5.—Section of 30,000 kW, 3,000 r.p.m. double casing turbine.

For larger outputs at 3,000 r.p.m. the design is illustrated in figs. 5 and 6 which show a 30,000 kW, 3,000 r.p.m. turbine. Owing to the very large volume of steam in the L.P. stages, the low pressure part is designed for double flow. By this arrangement the length of the machine is increased, and as it is good efficiency. At the same time the stresses in the rotating part are very low; hence it is easy to provide for a high factor of safety, even with very high steam temperatures. The casing diameter is obviously also small and again it is easy to produce a casing suitable for high pressures and temperatures.

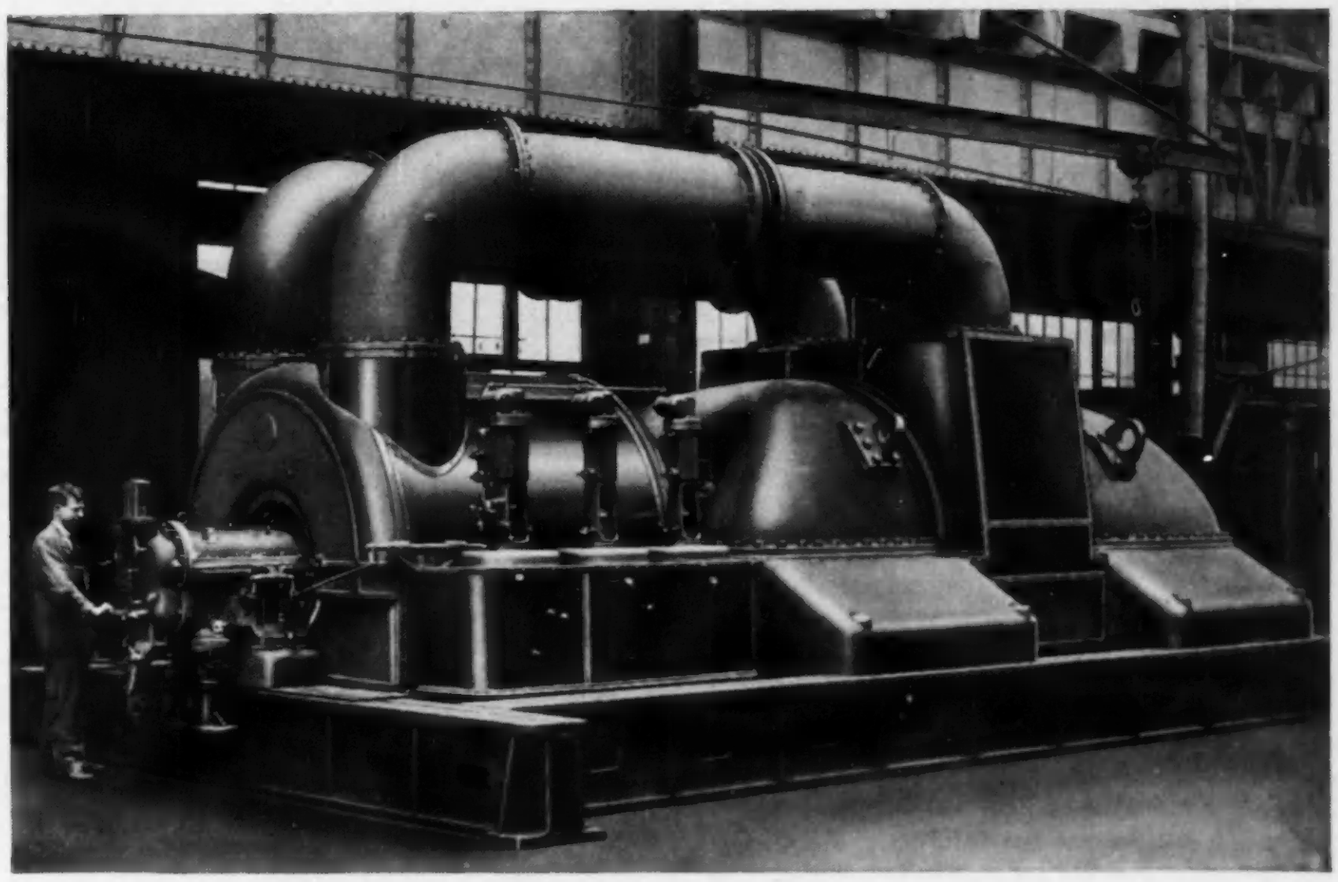


Fig. 6 —A 30,000 kW, 3,000 r.p.m. turbine on test.

impossible to produce a shaft of reasonable diameter having a critical speed above the running speed and carrying all the stages necessary for efficient operation, the machine is made in two casings.

The high pressure stages accommodated in the high pressure casing are all of small diameter and of the drum type. The small diameter results in substantial blade height, which is so necessary for

Between the two casings and on the exhaust of the low pressure casing is arranged a pedestal with two main bearings, a Michell thrust bearing and a rigid coupling.

It will be seen from fig. 5 that the steam is admitted to the high pressure casing at the end adjoining this centre pedestal. The exhaust of the low pressure casing is fixed longitudinally and the

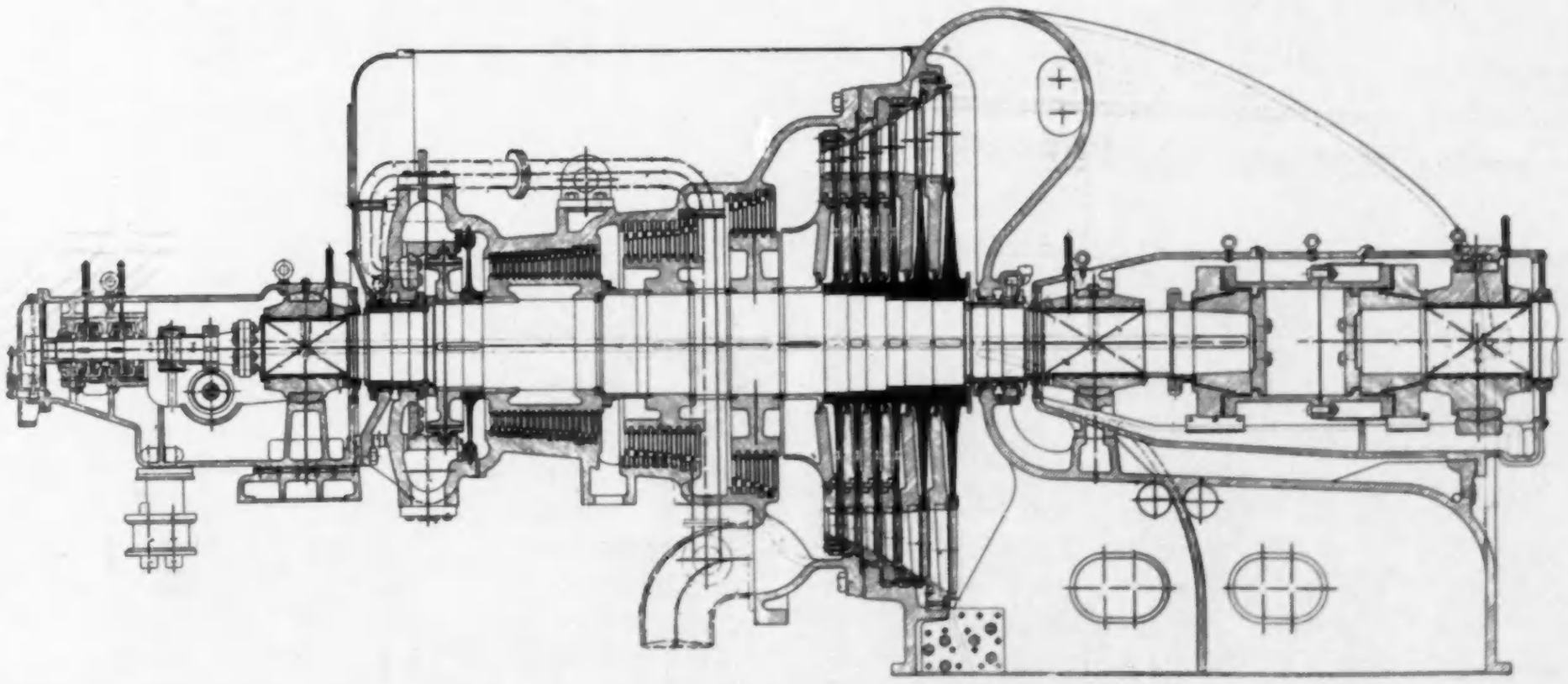


Fig. 7.—Section of 30,000 kW, 1,500 r.p.m. single casing turbine.

turbine expands longitudinally in both directions from this fixed point. The expansion is transmitted from the low pressure casing, through the centre pedestal, to the high pressure casing which at the far end is supported by another pedestal arranged to slide longitudinally on a soleplate. The expansion of the rotors takes place longitudinally in both directions from the Michell thrust bearing. In so far as the expansion of the high pressure casing and the stationary blade and the corresponding moving blade is made slightly larger. The other half of the low pressure stages from the point of view of expansion is identical with the ordinary single casing machines.

The provision of a single thrust bearing for the two rotors has the advantage that there is no relative longitudinal motion between the two shafts at the point where they are coupled together; hence a

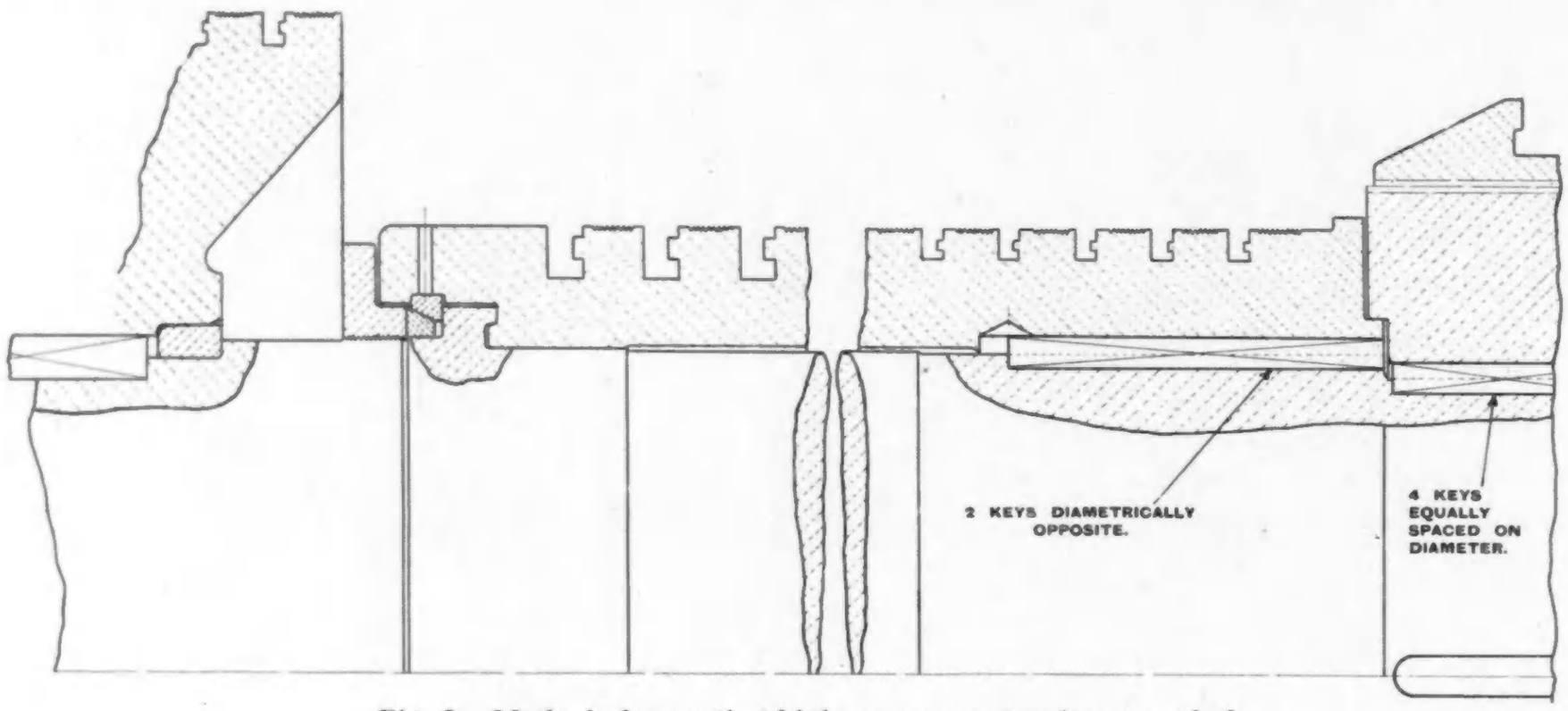


Fig. 8.—Method of mounting high pressure rotor drum on shaft.

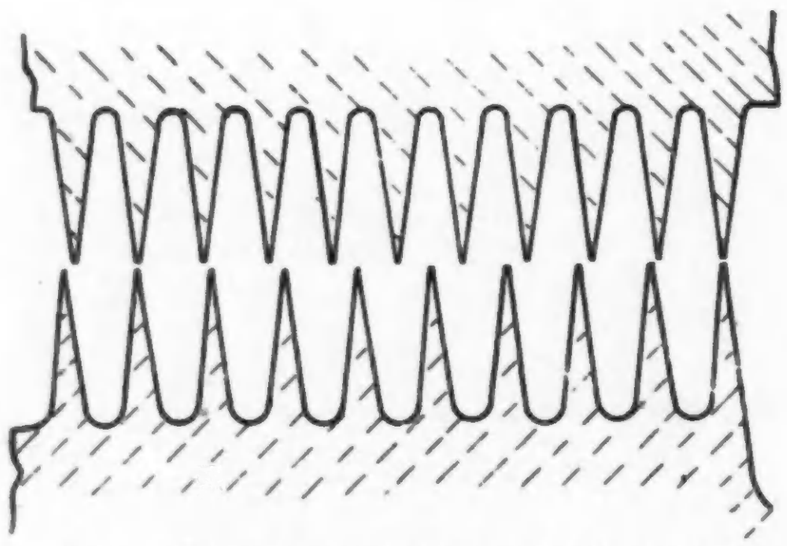


Fig 9.—Detail of packing fins for high pressure and low pressure packing.

rotor is concerned, it will be seen that they have the same relation as in ordinary turbines. Thus, should the rotor expand more than the casing, the moving blades move slightly away from their stationary blades, the clearance at the back of the moving blades being slightly larger to allow for such difference in expansion. The half of the low pressure stages nearest to the thrust bearing will have a comparatively small expansion, but when the shaft expands more than the casing, the moving blades of these stages approach their guide blades. In order to obtain complete reliability, the clearance between

rigid coupling can be applied with advantage. With a flexible coupling each rotor would require its own thrust bearing and, if there were a relative longitudinal motion in the flexible coupling, the grip of the coupling would cause the two thrust bearings to work against one another, a condition which might have serious consequences, especially with machines of very large output.

A steam turbine of 30,000 kW output at 1,500 r.p.m. is illustrated in fig. 7. Owing to the lower speed, a large number of stages can be accommodated in a single casing. The first stage is built

as a velocity wheel, the purpose of which is to provide for the possibility of nozzle cut-out governing, four throttle valves being provided, each controlling a separate nozzle block. The velocity wheel is followed by three drums of appropriate diameter to obtain the length of blades required for good efficiency, and, at the same time, a satisfactory ratio of the blade length to the diameter.

the admission belt communicates with a chamber extended to the boss of the cover. In this way uniform heating of the cover is achieved and dangerous heat stresses eliminated.

DRUM TYPE MACHINES.

An important point in the drum type machines is the construction of the drum itself. A typical

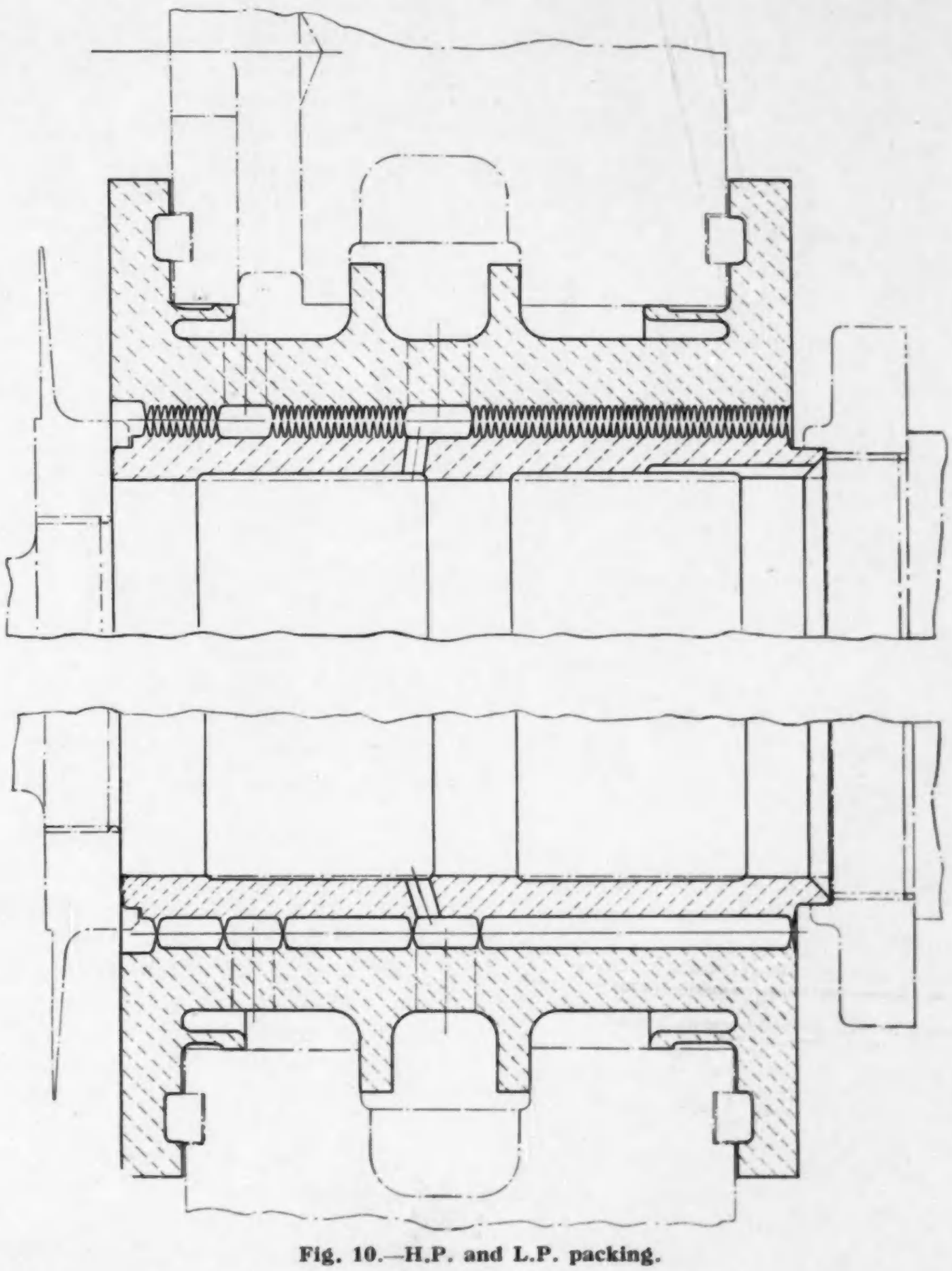


Fig. 10.—H.P. and L.P. packing.

The drums are followed by a number of disc type stages of large diameter so that the blade height, and the ratio of blade height to the diameter, is again kept within satisfactory limits.

In view of the larger diameter necessitated by the speed of 1,500, the high pressure end cover of the casing is designed in such a way that the steam from

design is illustrated in fig. 8. It will be seen that the drum is of moderate thickness and is entirely separate from the shaft itself. If the drum and the shaft were made in one piece the diameter would become rather large and, in certain circumstances, considerable temperature differences would arise between the outside diameter of the drum

and the centre. This would result in high heat stresses which might endanger the reliability of the turbine. A drum having a moderate thickness has heat stresses of negligible magnitude.

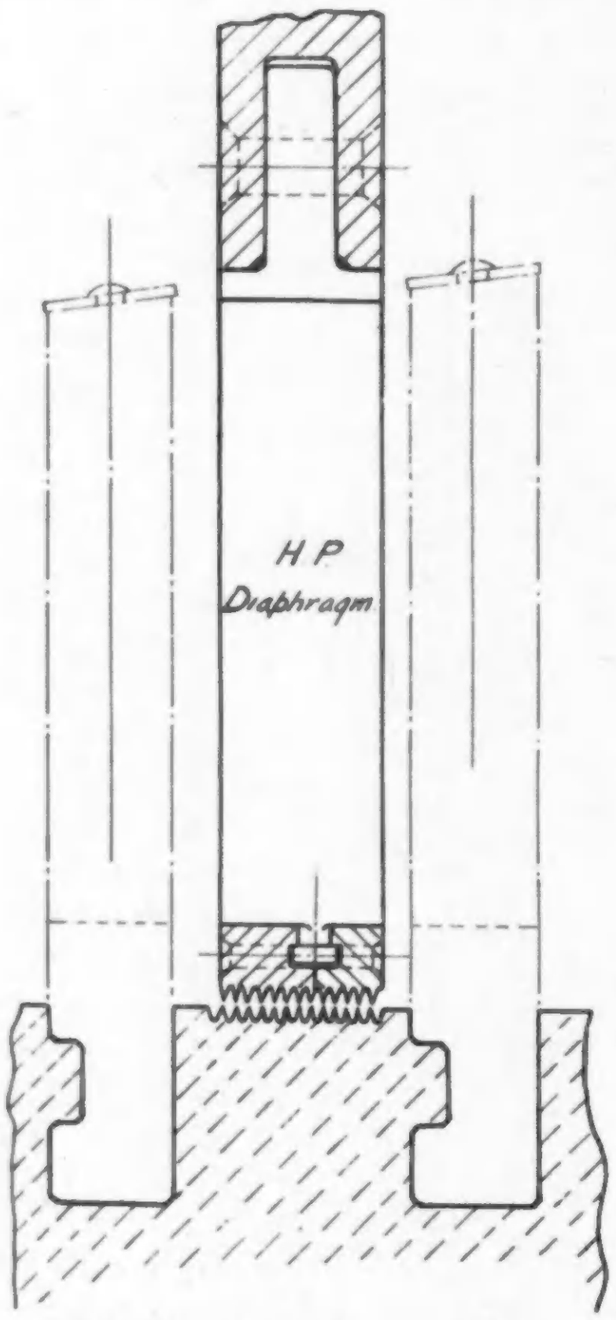


Fig. 11.—Rotor sleeve packing.

The shaft is protected by the drum from being heated unnecessarily by the steam. In this manner the heat stresses in the shaft itself are confined within small limits. Finally, should accidental contact take place between the drum and the stationary blade packing, the local heating would not be transmitted to the shaft, and hence there would be no tendency for the shaft to spring.

The drum has only a sliding fit on the shaft to which it is keyed for the purpose of transmitting the torque. At the high temperature end a small ring is provided which fits into a recess of a separate ring carried on the shaft by means of four keys arranged crosswise. These four keys centre the ring with the shaft, the expansion of the ring being otherwise free in all directions. The other end of the drum has also a small ring turned into it, this ring fitting into a recess cut in the solid shaft. At this end the drum is also fixed longitudinally. This is accomplished by means of two ring segments which are inserted into a recess inside the drum. The two segments are then pressed against the drum by a small ring pushed on the shaft, this ring being held in its longitudinal fixed position by means of a nut.

PACKINGS.

Another important point in modern steam turbines is the design of the packings. The steam pressure being higher and the expansion in the first stage being small, it is evident that efficient packings have greater importance now than in older machines. The principle of the labyrinth packing is shown in fig. 9. This generally consists of a stationary ring and rotating ring, each fitted with fins turned out of the solid. The edges of the fins co-operate and form the leakage area of the labyrinth packing. It will be seen from fig. 9 that the pitch of the fins is slightly larger on the one ring than on the other. Within a certain number of fins the leakage area varies ; the direction of steam flowing through them also varies. Should one ring

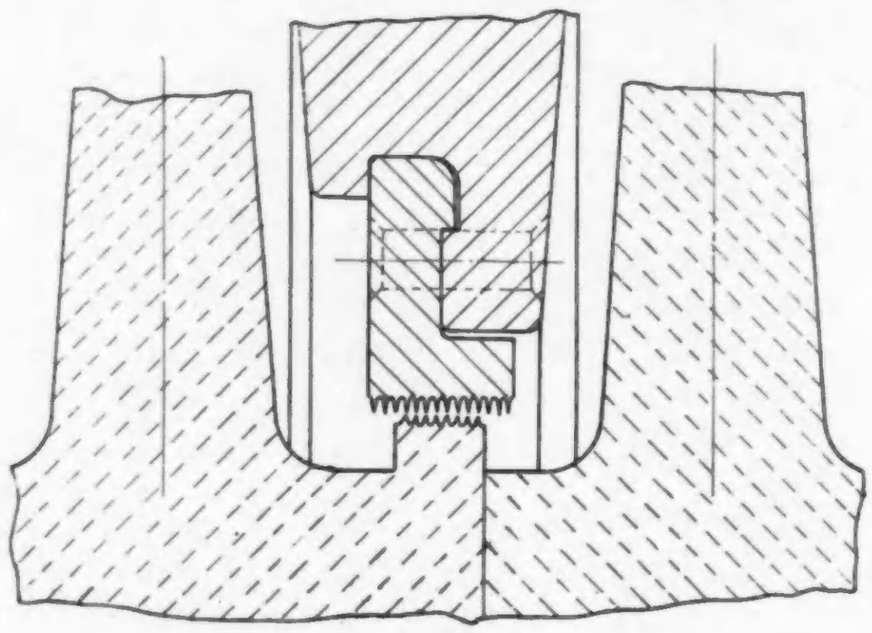


Fig. 12.—Low pressure diaphragm packing.

move longitudinally relatively to the other, the leakage through the packing does not appreciably vary as there will always be practically the same leakage areas but in different sequence. In view of the fact that the fins do not intermesh, it is possible to make the pitch very fine and thereby to accommodate a very large number of labyrinths within small longitudinal dimensions. Another important advantage of this labyrinth packing is that accidental contact occurs between a small number of fin pairs. As the contact takes place between two sharp edges, the heat generated is very small. Finally, the fins have a relatively larger surface which permits the heat generated by contact being easily carried away by the leaking stream.

This principle of labyrinth packing as carried out on the main packing at the point where the shaft passes through the casing is illustrated in fig. 10, while fig. 11 shows this packing as applied between the stationary blading and the rotating drum. Fig. 12 illustrates an inter-stage packing as applied to the disc type machine.

The Line Contact Air Break Circuit Breaker.

By A. SHERWIN.
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DURING the last two or three years much research and development work has been undertaken in connection with the design of air-break circuit breakers, with the result that new types have been evolved, having greatly improved characteristics. Of these new types, one of the most important is that designed by the late A. E. Angold, who, realising the limitations of the laminated copper brush used in most of the present-day designs, introduced his "line contact" circuit breaker, embodying a new form of laminated contact.*

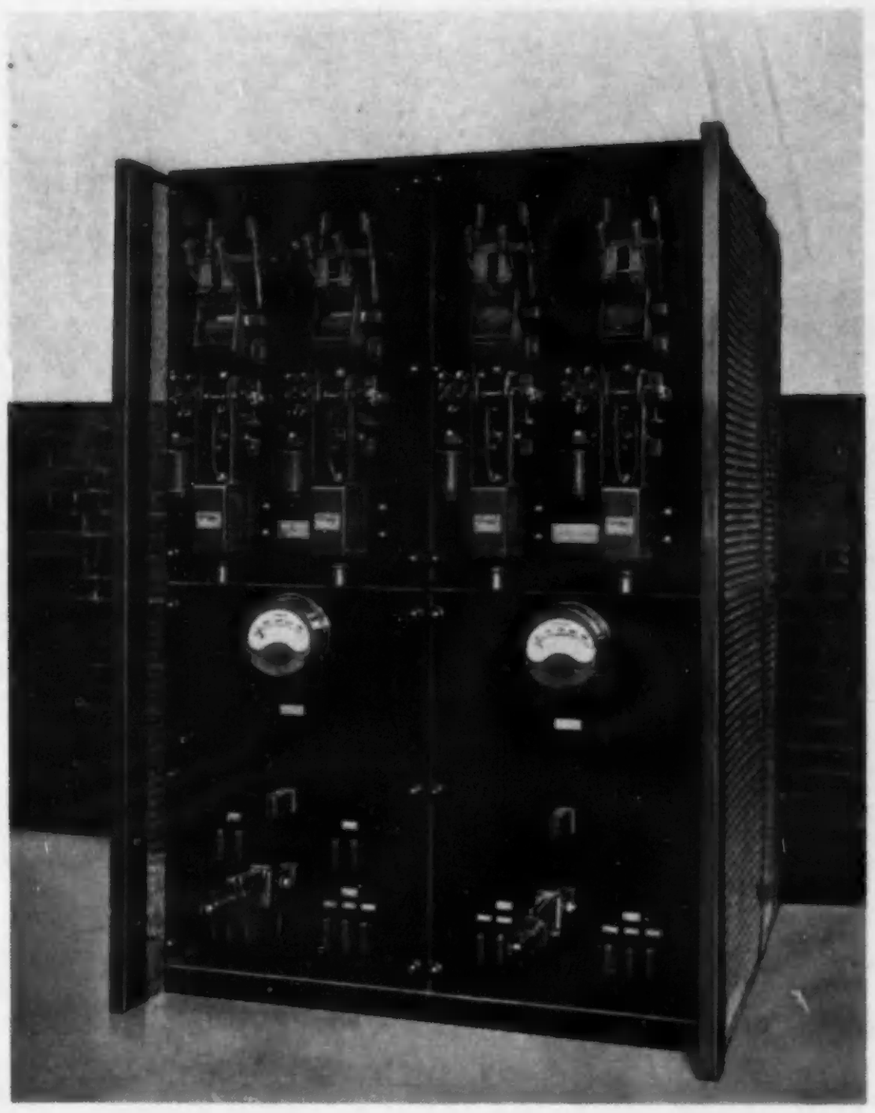

Fig. 1.—One of the auxiliary generator control boards at Hams Hall Power Station, Birmingham, equipped with electrically operated line contact circuit breakers.

In order that the importance of this new development may be appreciated, it is proposed briefly to review the main features characteristic of laminated copper brush circuit breakers; but, in indicating some of their inherent faults, it must be pointed out that this type of breaker has given excellent service in the past and is reasonably cheap to manufacture. Consequently it deserves, and still maintains, its popularity as a means of controlling circuits carrying moderate currents and subjected to no heavy overloads. It is only in recent years, during which the capacity of generating plant has greatly increased and circuit breakers have consequently been called upon to carry much larger currents, that such faults as exist have become more apparent, and the need for a new design has been felt.

DISADVANTAGES OF THE BRUSH.

The laminated copper brush which, as previously indicated, is used in most of the present-day air break circuit breakers, is formed from hard rolled high conductivity springy copper leaves cut from strip. The leaves vary in length and are assembled much after the style of a laminated carriage spring, but with the short leaves on the inside.

The brush usually consists of several identical units or packs of these leaves, bolted or clamped to an insulated carrier. Each leaf makes independent contact on both blocks, the actual contact taking the form of either a point or line. If the brush has been carelessly assembled a point contact is obtained while, if every lamination is parallel with the general curve of the brush and is cut off dead square at the end, a line contact results. In some cases the end of the leaf is bevelled right across in an attempt to obtain a maximum contact area, but as heat is likely to develop at the contact surface due to the inability of the leaf to penetrate the dirt and oxide film which eventually accumulates on the block, this practice is to be deprecated.

A common cause of brush failure is overheating, the brushes becoming discoloured and their flexibility destroyed by the very heavy currents they have had to carry during fault conditions. The trouble probably develops by stages, the inner leaves, which usually have to carry the most current by reason of their reduced length and greater pressure, failing first, thereby overloading the outer leaves. Moreover, the centre leaves of a brush are incapable of radiating much heat as each is sandwiched between two leaves at the same temperature, and its edge alone remains available for radiation. Thus, under heavy overloads, overheating may occur and the contact pressure rapidly disappear, as brass and copper are both softened at a comparatively low temperature. Further heat is generated as the

* British Pat. Nos. 290819 and 297164.

pressure is reduced, so that once deterioration has set in, the total destruction of the breaker is imminent.

THE LINE CONTACT CIRCUIT BREAKER.

In order to overcome these difficulties and in view of the fact that, for the reasons stated above, it may be expected that brush trouble will increase in the future, the line contact circuit breaker was evolved. In this, the brush is supplanted by a new form of contact, the laminations of which are in the form of Vee-shaped blades which bed into corresponding grooves in the contact blocks. The number of blades used for any particular breaker is determined by the current the breaker is designed to carry and, as a result of considerable experimental work directed towards discovering the most suitable Vee-angle and contact pressure, a high current-carrying capacity can be obtained without risk of breakdown. Two forms of this circuit breaker are illustrated in figs. 2 and 3.

Fig. 2 (*Left*).—**4,000 amp. electrically operated line contact circuit breaker with shunt tripping coil and three auxiliary circuit contacts.**

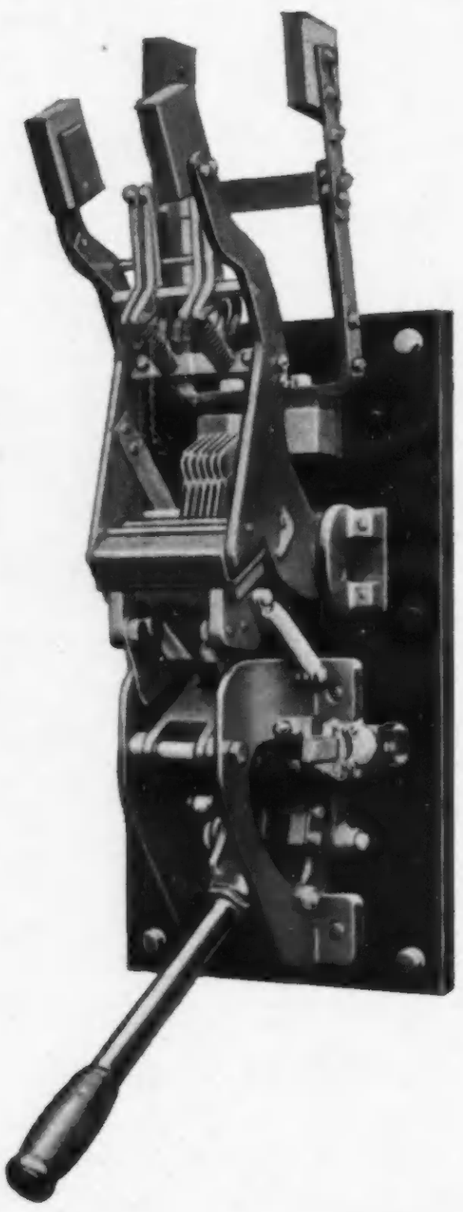

Fig. 3 (*Right*).—**500 amp. hand operated line contact circuit breaker.**

GENERAL CONSTRUCTION.

Each lamination or blade (A, fig. 4) measures $1\frac{1}{4}$ ins. by $\frac{1}{8}$ in. in section and carries 125 amps. The blades are carried by a horizontal steel thrust bar of special section (D, fig. 4). Pressed steel hook-shaped plates (C), securely riveted to the rear of the copper blades pass round the upper portion of the thrust bar in such a manner as to lock the blades securely in position but to permit their easy removal if necessary. The front edge of the copper blade is bevelled on both sides, the bevelled faces converging at an angle of 60 degrees, the upper and lower contact block being grooved at a corresponding angle. In order that the full pressure of the blade may be borne by the bevelled sides and full advantage taken of the wedging action, the leading edge of the blade is flattened so that it cannot bed at the bottom of the groove in the block (E). This has the further advantage of allowing any dirt which may collect on the block to escape instead of preventing the blade from making contact. The copper blade merely carries the current, the pressure maintaining the contact being provided by a stout steel spring (B), which is well removed from the source of heat. This spring is located between the steel plates and presses on the flat rear edge of the blade, the reaction being brought to bear on the thrust bar which is grooved to form a location for the spring. The provision of this spring, which locates the blade, constitutes an advance over the brush method.

BLADES.

The large amount of copper adjacent to the line of contact ensures that the heat there developed is rapidly conducted away and radiated by the large cooling area of the blade. This is assisted by

convection currents which pass upwards between the well separated vertical blades. The plates mounted on the blade limit the forward movement of the breaker by coming into contact with the back of the thrust bar, round which they pass. By this means the blades are firmly held, and as the spring is not allowed to relax fully, the energy required to close the breaker is considerably reduced. In this, the open position, the points of contact of the springs on the front of the thrust bar, and the plates at the

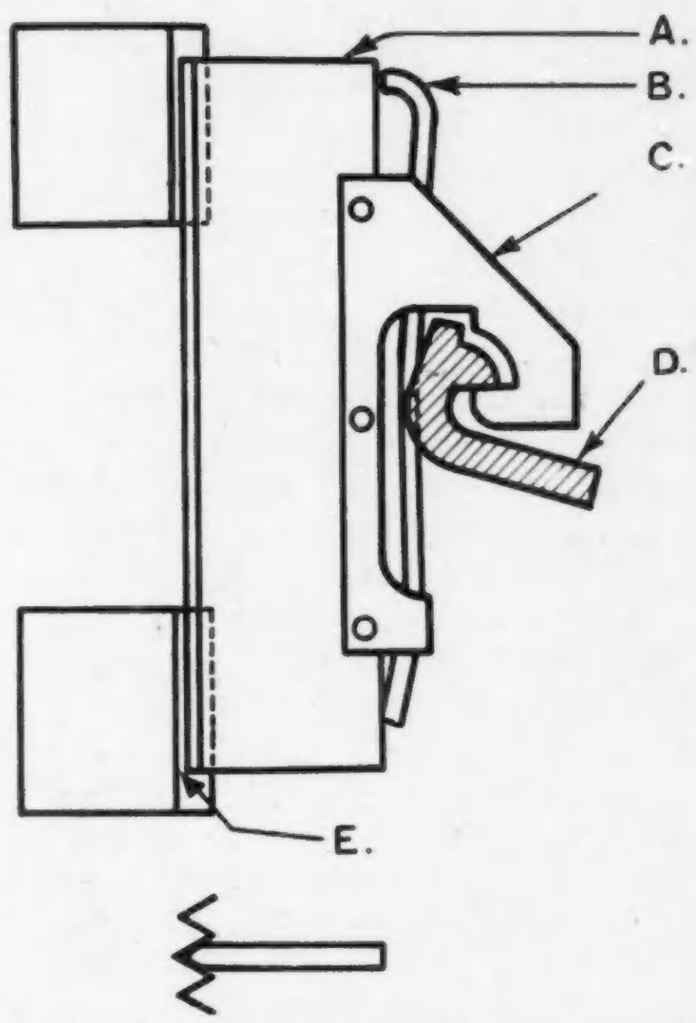

Fig. 4.—Diagram showing main constructional features of the line contact circuit breaker.

back, are so disposed as to keep the lower corner of the blade, which is rounded slightly, in firm contact with the bottom block. Each blade therefore carries an equal amount of the current passing through the arc as the breaker opens on overload, and the overheating of one or two blades is avoided.

The arrangement by which the contact blades are all mounted on a common thrust bar enables a standard width of breaker up to 6,000 amperes capacity to be manufactured. Above this capacity, the thrust bar is extended beyond the side frames and the extra blades are assembled on the extensions. The ventilation between the blades is particularly good and enables the larger breakers to work as efficiently as the smaller type and with equally low temperature rise.

BLADE PRESSURE.

The length of blade in contact with each block is one inch and therefore the length of line contact is two inches, or one inch per bevelled face. As each blade carries 125 amps. the density per inch of line is 62.5 amperes. The pressure per inch of line contact is 14 lbs., and is produced by the spring which exerts a total pressure of 28 lbs., or 14 lbs. at each end of the blade. This 14 lbs. is increased two-fold by the wedging action of the 60° faces, resulting in a pressure per face or per inch of contact of 14 lbs. as stated above.

VOLTAGE DROP.

The voltage drop from block to block when

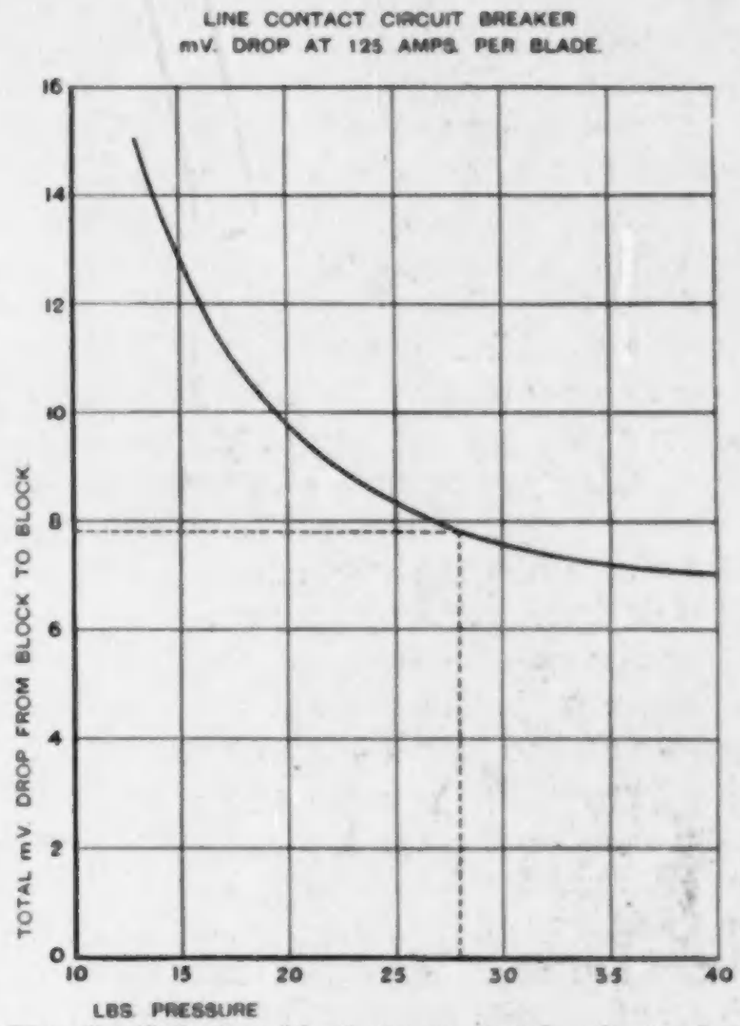

Fig. 5.—Relationship between total voltage drop and blade contact pressure.

each blade is carrying 125 amps. is 8 millivolts maximum, of which 2 millivolts are in the blade itself and 3 millivolts at each end of the blade, or at each contact surface. These results are due in part to a device which causes the blades to slide upwards in their grooves after contact has first been made. This sliding action is effected by an arrangement of the thrust bar which, during the last few degrees of movement, still retains a considerable vertical component, and its effect, combined with the wedging action, is to force the contact faces into intimate contact and to penetrate the dirt film.

In order to stress the importance of having sufficient contact pressure and to prove the effectiveness of the pressure at present obtained on line contact breakers, tests were made on a fully loaded blade by measuring the voltage drop at different pressures (fig. 5). At 28 lbs. the drop was 7.65 millivolts, whilst at 15 lbs. the drop rose to 12.7 millivolts. At this point the curve showed the relationship to be rising so steeply that at 13 lbs.

it had risen to 15 millivolts. As the drop is closely approaching the asymptotic value when the pressure is 28 lbs., the use of higher pressures is obviously unnecessary, as they would increase the energy required to close the breaker without increasing the electrical efficiency. These figures should be compared with the voltage drop of 20 to 50 millivolts given by brush type circuit breakers.

REMOVAL OF SPRINGS AND BLADES.

The upper end of the pressure spring, which is bow shaped, is ground to a cone and fits into a conical recess pressed into the rear edge of the copper blade towards the top. To remove a spring it is merely necessary to withdraw its upper end backwards and upwards so that it first becomes disengaged from the recess. This operation is carried out with the breaker open. The blade with its plates can then be removed, the time taken to change a blade being only a few seconds. This is a very desirable feature which will be much appreciated by supply engineers.

AUXILIARY AND SPARKING CONTACTS.

Up to this stage, attention has been paid to the main contacts only. The auxiliary and sparking contacts also embody some novel features. The auxiliary or intermediate contacts take the form of a number of copper fingers mounted at a radius from the brush arm spindle. These fingers are urged forward by springs which carry no current and are sufficiently powerful to provide the high angular acceleration demanded of the fingers as the breaker opens. A fixed bar is mounted above the upper contact block on which all the fingers press.

The carbon sparking tips, which break after the fingers, and are placed above them, do not butt together as is usual on circuit breakers, but slide one over the other. The mechanical pressure brought to bear on them is lighter than that usually applied to carbons, but on short circuits this pressure is augmented by the electro-magnetic force caused by the current and the disposition of the current-carrying arms on which the sparkers are mounted. The contacts are thus pressed together by a force which increases as the fault current grows.

Both the carbon sparkers and the metal fingers are capable of breaking heavy overloads without damage, and the sliding action of the carbons avoids the mechanical shock which, in the case of electrically operated circuit breakers fitted with butting carbons, is responsible for many breakages.

The contacts for making or breaking auxiliary circuits are operated by a link mechanism coupled to the thrust bar of the moving contact. This arrangement precludes the danger of auxiliary contacts functioning incorrectly. All the usual tripping arrangements may be fitted with the exception of the reverse current trip. This must be provided by means of a reverse current relay, a method generally conceded to be the safest, as it is independent of variation of voltage. In cases where the reverse trip is dependent on such methods as polarisation, voltage variation would affect the calibration; that is, if the voltage falls, the reverse current necessary to operate the breaker for any definite setting would increase.

CLOSING MECHANISM.

A double toggle free handle closing mechanism is fitted, the trip lever itself being brought out concentrically with the handle pivot so that it remains operative in all positions of the handle.

Electrical or manual operation can be applied and the design is such that the closing handle can easily be removed, making it impossible for unauthorised persons to close the breaker once it has been opened.

The width between the side plates carrying the toggle mechanism is standard for all sizes, while the location of the mechanism below is clear of the contacts and renders all parts accessible. The mechanism may be dismantled as readily as the contacts, and the catch withdrawn in a few seconds. The compression of the blade springs is adjusted by a right and left hand thread on the main toggle adjuster. The double toggles taken in conjunction with the method employed of locking up the reserve force in the contact springs enable the breaker to be closed with ease.

An air dashpot is used to absorb the mechanical shock when the breaker opens. It has been found that this method is more effective than the employment of snubbing springs in which the moving parts are gripped fiercely when the toggle, being fully collapsed, is incapable of transforming much force from the closing handle. In this position, if snubbers are used, considerable exertion is necessary on the part of the operator to free the moving parts. Snubbing springs are also impracticable on electrically operated breakers, in which, if the size of the closing coil is to be reasonable, the forces resisting the movement of the plunger at the commencement of the stroke must be reduced to a minimum.

FABRICATED CONSTRUCTION.

In the general design of this type of circuit breaker, there has been a definite leaning towards the latest practice of "fabricated" construction, all cast iron parts being eliminated and replaced by forgings or pressings bolted together to build the complete unit. This is particularly noticeable in the case of the side plates, which consist of single pressings. In the electrically operated breaker straps are provided for carrying the closing coil which is bolted to the base of the side plates.

As the pressures and necessary closing forces have been reduced, the strains transmitted to the panel on which the breaker is mounted are less than with the laminated brush type of breaker. It is thus possible to use a lighter panel while retaining the same factor of safety.